The Methodology of Geometric Order in the Design of Traditional Islamic Buildings

A Case Study of Madrasas in the Mamluk Eras in Egypt

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Abstract

The Mamluk madrasa in Cairo is said to be one of the best-preserved and understood of all buildings from the Mamluk era. Due to its well-preserved state the building has been the focus of a long and prominent line of research. Yet the geometric order in the building design still remains unknown and its geometric methodology of design has not been brought into a satisfying relation to any ancient design analysis. With a new approach this thesis could solve the problem of the building's geometric design. After analyzing the drawings of madrasa buildings, the inherent geometry principles for the design of the plans and the design of facades can be ascertained.

The research attempts to show through many examples that geometry can be employed in various ways in architectural design to provide solutions to the design problems. In this way, the research can show that geometry is a universal code or language that every discipline can use. Although we have a large body of historical examples to study, we do not know exactly how architects working at that time designed their madrasa buildings. Thus, we are left with the exciting historical puzzle of uncovering lost geometrical techniques, or inventing new ones altogether. The research is interested in understanding how madrasa buildings may have been designed in the first place by the aid of geometry. The research started a process of geometric decoding for Mamluk madrasas beginning with understanding the geometric methodology of design which were used.

One of the most important findings of the research is that the madrasa buildings were designed along the lines of geometry based on axes and angles, and they have geometric steps in every design step, so the research tries to blow away the dust from above the layer of geometry in Mamluk architecture, in order to present the important role of geometry in Mamluk architecture in general and make the madrasa building design more understandable in particular. The most concern for this research is making this layer more clear and understandable besides asserting that these geometric models remain the backbone of the process of "designing" of Mamluk religious buildings, and also asserting that geometry is the most important key to understanding the philosophy of Mamluk design theory.

The research skeleton is divided into three main parts. The first part is the introduction, which demonstrates the roots of the research problem, the objectives which the research attempts to reach, the research questions, the research hypothesis, the research limitations, the research general considerations and the research methodology for dealing with the research problem. The second part is the theoretical study, which begins with a close look at the design method and demonstrates the relationship between geometry and architecture in Islamic architecture. Then it sheds light on Mamluk religious architecture before going on to focus on the geometric design of madrasa buildings during the Mamluk period. It finally ends with the suggestion of the geometric methodology of design in Islamic architecture by presenting a geometric generative technique for madrasa building design. The third part is the analytical study which begins by applying the geometric generative technique to the case-study buildings and ends with a recommendations and proposal for future work. Finally, the research demonstrates a computer-aided generator program as a presentation tool to help readers understand how the geometric generative technique could be applied to the case-study buildings.

Die Methodik der geometrischen Ordnung im Entwerfen von traditionellen islamischen Bauten

Eine Felduntersuchung Madrasas in der Mamluken Eras in Ägypten

Kurzfassung

Die Mamluken Madrasa in Kairo gilt als eines der besterhaltenen und meiststudierten Gebäude aus der Mameluken-Ära. Wegen seines guten Zustands ist das Gebäude Gegenstand einer langen und prominenten Geschichte der Forschung. Trotzdem bleibt das geometrische System des Gebäudes immer noch unerforscht und seine geometrische Entwurfsmethodik konnte bisher in keine befriedigende Beziehung zu anderen alten Methoden gebracht werden. Mit einem neuen Ansatz, *AOS geometrischen Design,* versucht die vorliegenden Arbeit die Fragen hinter der Geometrie des Gebäudes zu beantworten. Nach einer Analyse der Pläne des Gebäudes, konnten die inhärenten geometrischen Prinzipien für den Entwurf von dem Grundriss und den Ansichten ermittelt werden.

Die vorliegende Arbeit versucht anhand ausgewählten Beispiele zu zeigen, wie die Geometrie benutzt werden kann, um Antworten und Lösungen zu geben, die über die der geometrischen Homogentität der Gebäudekomposition hinausgehen. In dieser Weise, versucht diese Arbeit zu demonstrieren, dass die Geometrie nicht irgendwas Fremdes ist, sondern eine universeller Code oder eine Sprache, welche in jeder Diziplin zur Verfügung steht. Obwohl uns eine große Menge historischer Exemplare zur Verfügung stehen, wissen wir nicht genau, wie Architekten zu jener Zeit die Koranschule konzipierten. Ihre Methoden wurden in der Regel als Zunftsgeheimnisse gehütet. Uns ist also das spannende historische Puzzle überlassen, alte Techniken aufzudecken, oder sie gar Neu zu erfinden. Diese Arbeit versucht zu verstehen, wie Madrasa Gebäude überhaupt entworfen waren, und darüberhinaus, zu spekulieren, wie, angesichts unseres heutigen Wissens und unserer Werkzeuge, wir auf diese Methodik aufbauen könnten.

Eines der wichtigsten Ergebnisse der Forschung für diese Arbeit war, dass die Madrasa Gebäude nicht nur in ihrer Gesamtkompositionen auf grundlegenden Geometrien aus Achsen und Winkel entwickelt wurden, sondern, dass sie durch geometrische Entscheidungen in jedem Entwurfsschritt bestimmt waren. Die vorliegende Arbeit versucht eine neue, umfassendere Sicht auf die Rolle der Geometrie in der Mamluken Architektur zu geben, zuerst in dem sie die wichtige Rolle der Geometrie in Mamelucken Architektur im Allgemeinen präsentiert, und dann im Besonderen, durch die vertiefte Untersuchung der Bauplanung der Koranschule. Einer der Hauptanliegen dieser Arbeit ist es, diese geometrische Schicht freizulegen, sie klar und verständlich zu machen. Zudem soll gezeigt werden, wie traditionelle geometrische Modelle das Rückgrat im Prozess des

Enwerfens von Mamluken Sakralbauten bilden, und darüberhinaus, dass die Geometrie der wichtigste Schlüssel zum Verständnis der Philosophie der Mamlukischen Entwurfstheorie bleibt.

Die Arbeit ist in drei Hauptteile gegliedert. Der erste Teil ist eine Einführung, welche folgendes darlegt: die Geschichte der Forschung, die Ziele der Arbeit, die Fragestellungen, die Forschungs-Hypothese, die Forschungs-Beschränkungen, und die Forschungsmethodik. Der zweite Teil ist eine theoretische Studie, welche zuerst die Rolle der Geometrie in der islamischen Architektur erläutert. Nach einem Blick auf die religiöse Architektur der Mamluken, wird dann auf die geometrische Gestaltung der Madrasa Gebäude während der Mamlukenzeit konzentriert. Der zweite Teil endet schließlich mit einem Vorschlag für eine geometrische Entwurfsmethodik in der islamischen Architektur durch die Vorlage eines generativen geometrischen Verfahren zum Entwurf einer Koranschule. Der dritte Teil ist eine analytische Studie, welche mit der Anwendung der generativen geometrischen Technik am Fallstudie-Gebäude beginnt. Er endet mit einem Fazit, Ergebnissen, Empfehlungen und Vorschlägen für die künftige Arbeit. Schließlich wird ein computergestütztes Generator-programm presentiert, welches den Lesern demonstriert, wie die generative geometrische Technik für weitere Fallstudien angewendet werden könnte.

Acknowledgements

First and foremost, praise and thanks be to God the Almighty for having made the achievement of this study possible. I would like to thank, first and foremost, my father **Eng. Ali Ahmed Gaber** (God bless him), who preferred to face death without seeing me beside him during his illness rather than interfere with my concentration on my Ph.D. by visiting him in Egypt.

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Last but not least, to my family in Egypt, I lovingly dedicate this work. I am eternally grateful to them for their encouragement and patience throughout this period and I sincerely hope to find other ways than mere words to show them my gratitude. Special thanks should go to my brother **Dr. Emad Gaber** for his support and taking care of our father (God bless him), during my scholarship in Germany. I would also like to thank my brother **Mr. Mahmoud Gaber** for his great care with my mother, **Mrs Soad Mahmoud**, and my sisters, **Noha and Ola** during my absence. This dissertation is dedicated to my wife **Mrs. Asmaa Dahi** for her love, support and encouragement throughout this difficult journey, and finally to my children, my lovely son **Mazen** and beautiful daughter **Raneem**.

All thanks and praise are due to Allah, My Almighty God, My Creator and Sustainer for everything I ask and I do not ask, for giving me life, knowledge, and faith, and peace be upon his messenger Muhammad.

Ahmed Ali Gaber
Karlsruhe, 06/07/2011

Dedicated to:

My big family, the Muslim community:

And to

My Father's Soul and my Mother

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System of Transliteration

Arabic letters	Transliteration	Arabic letters	Transliteration	Short Vowels	
ء	’	ظ	ḋh		
ب	b	ع	‘	◌َ	a
ت	t	غ	gh	◌ُ	u
ث	th	ف	f	◌ِ	i
ج	j	ق	q	**Long Vowels**	
ح	Ḣ ḣ	ك	k		
خ	Kh	ل	l	ى/ا	ã
د	D	م	m	و	ũ
ذ	Dh	ن	n	ي	ĩ
ر	R	هـ	h	**Diphthongs**	
ز	Z	و	w		
س	S	ي	y	◌َ و	aw
ش	Sh			◌َ ي	ay
ص	Ṡ ṡ			ـٓ	iyy
ض	Ḋ ḋ			و	uww
ط	Ṫ ṫ				

Dating

The method of dating used in this thesis incorporates the *Hijirĩ* date A.H. followed by the Roman Calendar date A.D. between brackets. In some cases, only one of the two dates is used; this is due to the absence of information on the lunar month, which if approximated in the *Hijrĩ* calendar, may result in misleading conversions.

Illustrations

All illustrations incorporated in the text of this thesis are the author's own, except when stated otherwise. Where plans have been redrawn, corrected or edited, the word *After* followed by the name of the author or source is added between brackets after the caption.

All the photos and images in the text of this thesis are from the following sources:

- Taken by the author himself during the field visit to Islamic Cairo.
- Many internet websites (such as Archnet.com, Flicker.com and Egyptarchitecture.com).
- Two main books: ("Cairo of the Mamluks: A History of Architecture and its Culture" published in Cairo, Egypt, 2007 by Doris Behrens-Abouseif, and "The Art and Architecture of Islamic Cairo", published in Reading, UK, 2006 by Richard Yeomans).

The plans which the thesis relied on it for the analytical study are from the book "Principles of Architectural Design and Urban Planning During Different Islamic Eras" published in Jeddah, Saudi Arabia, 1992, by the Organization of Islamic Capitals and Cities (OICC).

Research Skeleton

Design Method

Geometry

Islamic Architecture

Introduction

The first part — **The Theoretical Study**

- Chapter 1: Literature Review
- Chapter 2: The Mamluk Religious Architecture
- Chapter 3: Geometric Design in Madrasa Buildings
- Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part — **The Analytical Study and the Field Study**

- Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings
- Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A — **A Computer-Aided Generator for Madrasa Buildings Design**

1- Prologue

Every civilization has its architecture. Any civilization's progress can be read through its architectural heritage, because architecture is the written history of any community. Architecture may be studied as an extension of man, a visual representation of how man creates his buildings to suit the environment, an art form, an expression of man's ideals and desires, or as an expression of geometry applied to structures. Nothing can make an eloquent statement about a community better than its architectural heritage. Egypt, through its long history, has displayed a diversity of cultural and architecture expression that produced an enormous number of buildings reflecting several cultures and achievements of societies. These architectural expressions are the heritage of Egypt and the Mamluk architecture expression became the one which flourished the most among them. This research focuses on the architecture of the Mamluk period being a true expression of a rich culture that produced plenty of buildings that influenced later generations.

The growth of Cairo during the Mamluk period meant that most types of building, even palaces, were located within the fabric of a city. The result of this was that buildings were often built on an irregular-shaped plot because of the shortage of space. Many Mamluk buildings which seem to be square and orderly were built on irregular ground plans. **So the question is**: How did the Mamluk architect manage to place the same design for the madrasa buildings in differently shaped building sites? What is the hidden factor which helped him in designing the same building or the similar functions' programme to accommodate the varying conditions of the different sites? **The suggested answer is**: There are constant models or rules for the design he applied regarding the building site conditions. This model and these rules produced the similarity in building design at the different sites in the city fabric. The research problem emerges from this point and the attempted solution is to suggest a geometric generative technique model for madrasa building designs from the Mamluk era. This model depends mainly on geometric rules, geometric principles and geometric criteria.

Geometric design is one of the most distinctive aspects of Islamic art and architecture. Geometric decoration can be seen everywhere in the Islamic world: on buildings, in books, on tiles, on wood, and on metal. The variety of modes of application of geometric design is endless; it has been practiced for centuries in all parts of the Islamic world, with craftsmen transferring their knowledge from one generation to the next. **Little is known about architectural design techniques in the Mamluk era or how Mamluk architects made the geometric compositions in madrasa building design; however, their designs provide us with a great deal of information and insight.** From the analysis of the Mamluk madrasa building design the research aims to engender a better understanding of the geometric order behind the architectural design of religious Mamluk buildings and the reason why the Mamluk design style is constant during the Mamluk era.

The initial investigation of the field reveals that the geometric aspects of madrasa architectural design have not been adequately described in the architectural or design process literature. Consequently, an empirical study is set up for the purpose of gaining a deeper understanding of the strategies that guide Mamluk design processes. This research attempts to develop a geometrical analytic approach to understanding the geometry that inspires Mamluk architecture. At the heart of this approach lies the consideration of the relationship between geometry and architectural design, and its application to provide a practical method for form making and developing systems of composition. The research aim is to "**outline the geometric concepts of composition and the process of their application in different steps of the architectural design process of madrasa buildings**". This is essential not only for the process of Mamluk architectural design but also for its understanding. This is the meaning by which architecture has sustained its distinct characteristics throughout history despite the cultural diversity of the Mamluk world

2- Research Problem

From studying and researching Islamic architecture the following observations have been found:

* There are many studies on Islamic decoration and ornamentation, but fewer on Islamic architectural design, specifically on the geometric design of madrasa building in Mamluk architecture.
* There is no study dedicated to the field of geometric order in building design in Mamluk architecture which provides the basis to discover some of the profound knowledge used in madrasa buildings architectural design.
* There is no specific and clear methodology explaining the geometric order in the design of madrasa buildings in Mamluk era.
* There is no study demonstrating the geometric technique which the Mamluk architect utilized to generate the design of madrasa building.
* There is no study demonstrating the hidden geometric systems applied in the architectural design of madrasa buildings.
* There is no study demonstrating the concept of geometric relations resulting from mathematical relations in the architectural design of madrasa buildings.

From all these observations of Islamic architecture the research problem emerges as a question that this research will try to answer:

What is the Geometric Order (if any) that Controls the Design of Madrasa Buildings during the Mamluk Era?

3- Research Objectives

The research has the main general objective as follows:
to "demonstrate the methodology of geometric order in the design of madrasa buildings in the Mamluk era". To reach this objective the research must achieve the following two main objectives:

The first main objective is to "**discover the geometric generative techniques"** which the Mamluk architect used in the **design process of madrasa buildings**.
The research refers to the building **plan design** (2D design), the buildings **spacial design** (3D design) and the building **facade design** and **decoration design**), as "**building design**".

So the research aims to discover:-

a- The geometric generative techniques for the plan (2D design)
b- The geometric generative techniques for architectonic space (3D design)
c- The geometric generative techniques for the facade

The Second main objective is create or suggest **"a computer-aided generator program",** which demonstrates the geometric order in the design process of madrasa buildings.
In order to achieve these main objectives three sub-objectives have been formulated:
The First: Determine the **Islamic architectural design principles** which control and govern the architect's thinking during the design process.
The Second: Discover **"the hidden geometric design system"**, which had been applied to the madrasa building design.
The Third: Demonstrate **"a spatial disposition system of different functions and spaces"** in madrasa buildings.
In general, the research attempts to achieve the following objectives:

* Search for and find the roots of Mamluk architecture.
* Search for and find a way of thinking in Mamluk architecture.
* Determine specific geometric rules for the design of complex buildings.
* Work out a standardized geometric methodology for future building design.

The following figure presents the general field of the research, main focus of the research, the case-study buildings, and the research objectives.

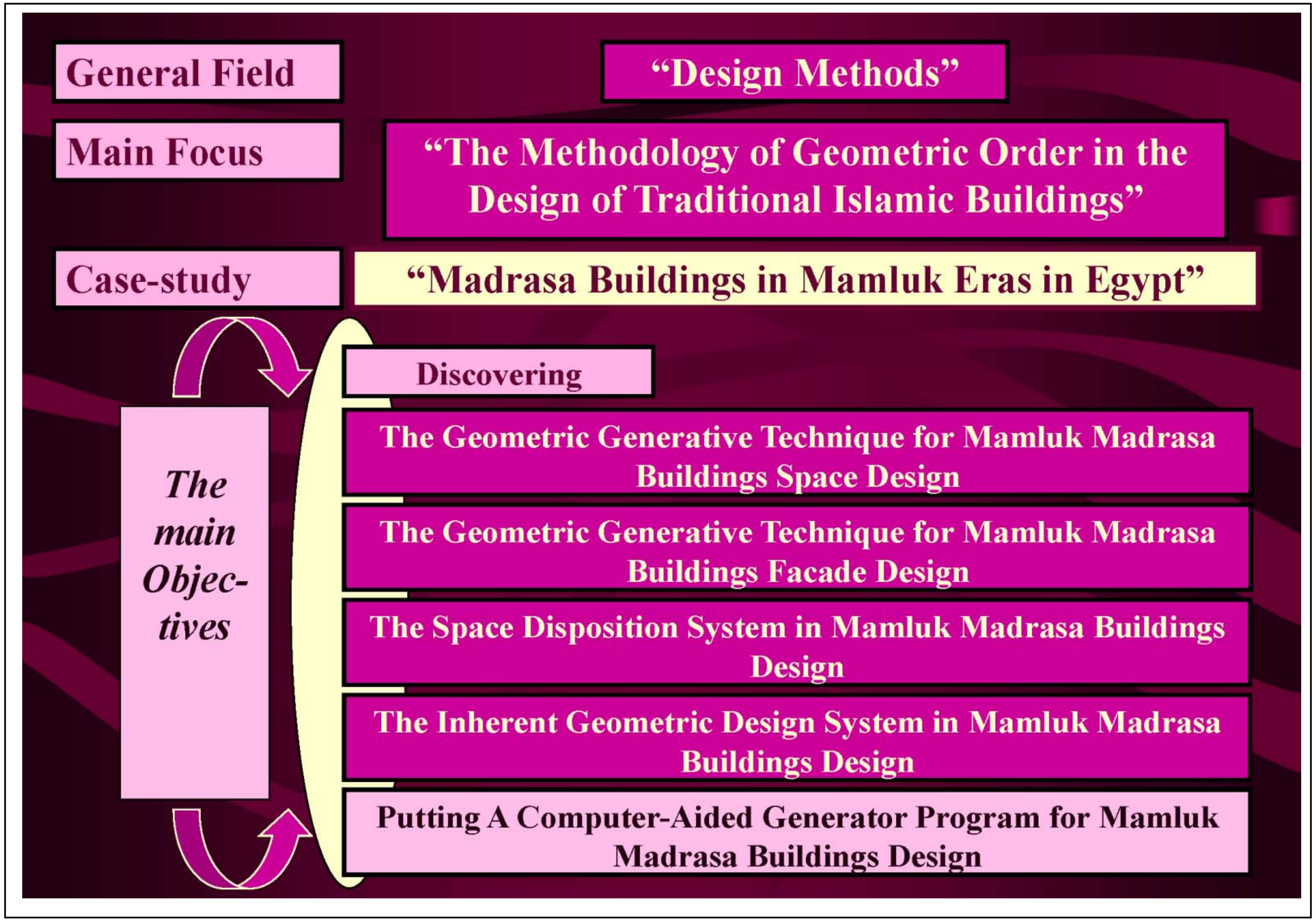


Fig. (1) The main objectives of the research

4- Research Questions

The research attempts to answer the following questions:

- What is the role of geometry in the design of madrasa buildings?
- How did the Mamluk architect design his madrasa buildings?
- How did the Mamluk architect design his madrasa buildings by using geometry?
- Are Mamluk madrasa buildings designed and shaped by hidden geometric codes?
- Is there a geometric order applied actively in Mamluk architecture in general and in madrasa architecture in particular?
- What were the stages of the design process he used in generating his madrasa design?
- What were the technical procedures or the geometrical methods of design used by Mamluk architects in madrasa architectural design?
- What was the hidden geometric system used in the design process of madrasa buildings?
- What was the architectural hidden geometric scheme used in the design process of madrasa buildings?
- What was the geometric shape grammar of madrasa architecture?
- What were the geometric principles used in space design and facade design in madrasa buildings?
- What were the primary geometric elements of space forming in madrasa architecture?
- Are there certain repetitive geometric relationships in the design of madrasa buildings?
- What are the intentions of the madrasa-designing architects behind forming the building to be almost square, octagonal etc. in its ground plan, and the arches being almost equilateral triangles?
- What are the geometric meanings which are embodied in madrasa architectural design?
- What were the effects of the urban context in the design process of madrasa buildings?
- How did the Mamluk architect generate the spatial design in madrasa architecture?
- Which kind of studies helped him generate his madrasa design?
- Which branches of science must the Mamluk architect have studied in order to generate designs such as these?

5- Research Hypothesis

The research has six main hypothesises:

1- The **geometrical approach** is amongst the keys to a better and fuller understanding of the ideas behind the designs of the Mamluk period.
2- There is a **geometric order** in Mamluk architecture that is translated into a **geometric model** associated with the design of madrasa buildings in the Mamluk era in Cairo.

3- The architectural design of madrasa buildings is primarily based on **geometry**, specifically the design based on the simplest regular polygons, which had developed from the square as the simplest geometric figure.
4- A fundamental principle in Mamluk architecture is **the functioning and composition** of madrasa buildings **following geometry**.
5- The **inherent geometry** in Mamluk composition is the **design code**, and it can be determined through by the analysis of the Madrasa **geometric design** and by understanding the **geometrical methodology** in the building design process.
6- The **geometrical analysis** of historical buildings is an alternative tool for **uncovering the profound knowledge** of traditional master-builders in their works, to **improve the modern theories of design** and to set new design criteria.

6- Research Limitations

Which time, place and type of buildings is the research concerned with?

a- Why the choice of the Mamluk period:

There are numerous reasons for choosing the Mamluk period:

1- It is the most glorious period of Cairene Islamic architecture; so many historians name it "the golden age of Islamic architecture in Egypt".
2- It is the second longest of the Islamic architectural ages in Egypt, covering more than 250 years of the governance of Egypt. It is also well documented, so a large quantity and variety of available information is easily gathered. This has allowed for an immediate analysis to be carried out.
3- A holistic unity is sensed in Mamluk buildings more than in those of earlier periods in Cairo, so the geometric principles of design will be determined clearly.
4- Many buildings from this period are still intact.
5- Many additions to the Islamic architectural character were added during this period (for example, to solve the problem of maintaining the spatial and visual continuity between the interior space and the exterior multi-use urban structure, the Mamluk architect developed an indirect entrance as part of the transitional space, introducing the use of surprising architectural elements as an important factor improving the recognition and the experience of the building in the memory of the users, and designed the building in such way so as to address the street and the image of the city as a whole).
6- Political and economic stability during this period led to the encouragement of the building process.

b- Why the choice of the madrasa type:

There are many reasons for choosing the madrasa building:

1- It is a public building, with a variety of public uses (it is a religious, educational and residential building at the same time) and has an important role in the urban fabric.

2- Almost all Mamluk rulers built them, so they allow us to formulate a good picture about the Mamluk architectural style, not only at a certain point in the Mamluk era, but during all of the periods of Mamluk governance.
3- It allows not only the study of one type of building but many types in one building at the same time.
4- It is a unique type of building found in large numbers in a very clear phase in this era of Islamic architecture, so there is possibility of generalized conclusions.
5- Its architectural design demonstrates many Mamluk additions to Islamic architectural character.
6- It should lead us to discover how Mamluk architects dealt with complex building design geometrically.

C-Why the research focuses on geometric analysis methodology:

There are many reasons for choosing the geometric analysis methodology:

1- In Mamluk decoration there is a rich variety of distinctive styles of formal geometric design. This means that Mamluk architects were very aware of formal geometric composition and that the architectural design finds a starting point in the understanding of the geometric creation process of form. Moreover, this means that the geometric analysis provides a good understanding of formal composition.
2- The use of the geometric analysis methodology offers a new and alternative approach for the study and analysis of historic Mamluk architecture, with a focus not on chronology, building style or type, but on design methods and design complexity.
3- By means of geometric analysis it is possible to understand how the individual spaces in the work of architectural design can be arranged, and how the designer can solve the complex relations between different spaces.
4- The analyses of the relation between different geometric space concepts and the architectural design processes are fascinating fields and have become more and more important in recent architectural designs.
5- The transformational operations which can be carried out on the different geometric space concepts and geometric forms can create a good background for architects to begin with the architectural design process.

7- Research Methodology

In order to achieve the research objectives the study is divided into three main parts: an introduction and two main sections, which are subdivided into six chapters

* **The introduction** defines the problem and its different dimensions, and clarifies the objectives, the hypothesis, the methodology and skeleton of the thesis.

* **The first part** contains the theoretical study in four chapters, and ends with the suggestion of a geometric methodology of design in Islamic architecture.

* **The second part** includes the analytical and field studies and their consequences divided into two chapters.

The research methodology uses or depends on two ways or methods of thinking:

The First: Top-Down approach

This approach depends on looking at the design problem generally and then delving inside it to reach its main component.

The Second: Call-Return approach

This approach depends on beginning from the design problem's main component and going up, step by step, to reach the final solution of the design problem.

The research methodology's ways of thinking are shown in the following figure.

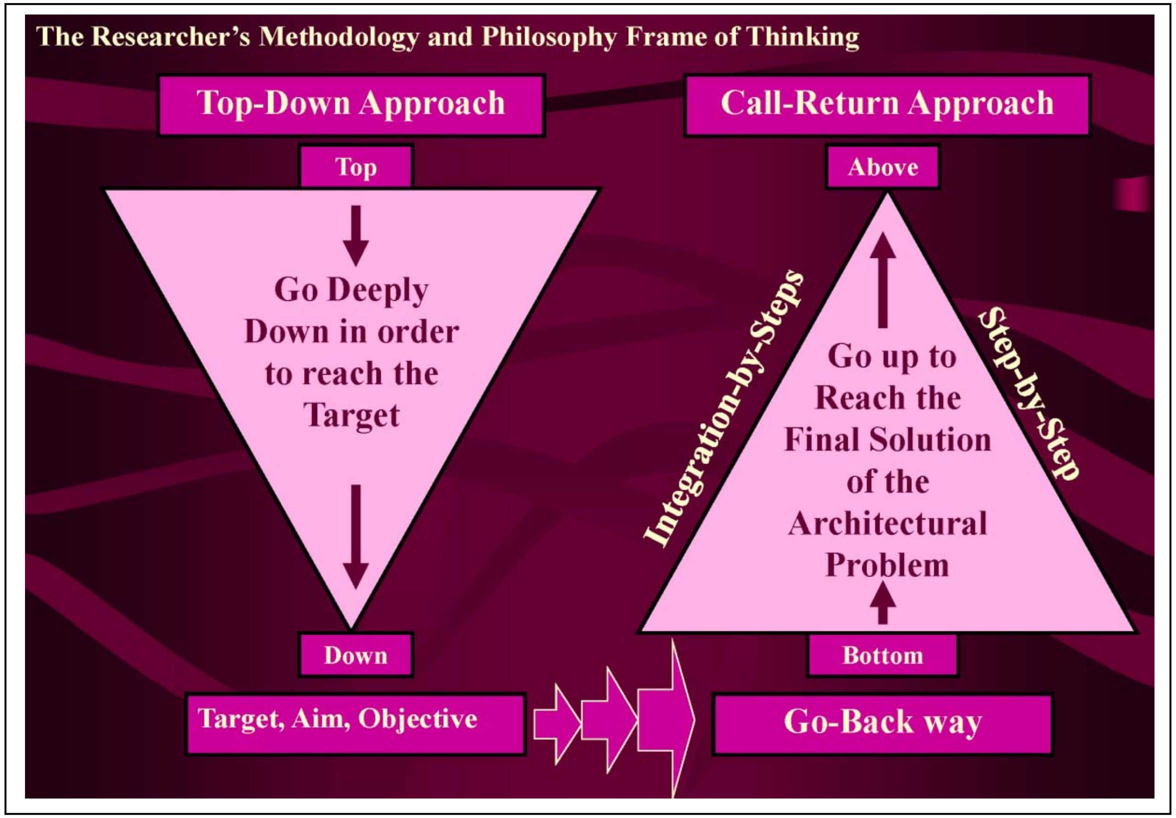
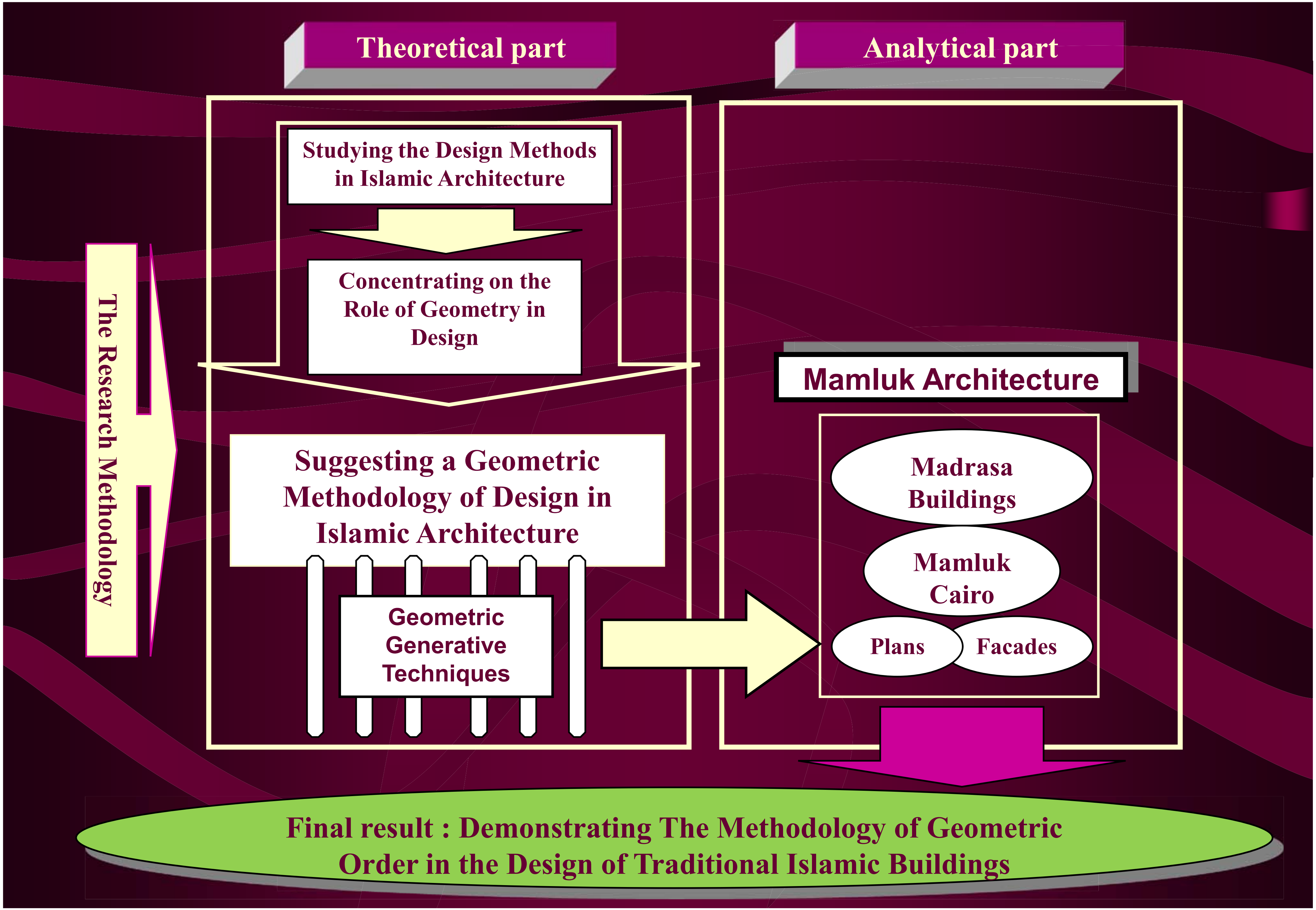


Fig. (2) The researcher's methodology and philosophy frame of thinking

The following figure presents the research methodology and how the final result of the research could reached through the research steps.


Theoretical part
Analytical part
The Research Methodology
Studying the Design Methods in Islamic Architecture
Concentrating on the Role of Geometry in Design
Suggesting a Geometric Methodology of Design in Islamic Architecture
Geometric Generative Techniques
Mamluk Architecture
Madrasa Buildings
Mamluk Cairo
Plans
Facades
Final result : Demonstrating The Methodology of Geometric Order in the Design of Traditional Islamic Buildings

8- Research Importance

The research in madrasa design gains its importance due to the following reasons:

1- A study of geometric methodology of madrasa design is surely of great use, since there are only few specialists who have an overview of the relations between geometry and space design of multi-functional buildings.
2- A study of design methods in Mamluk era offers an a nalytical understanding to the geometric transformations that may have appeared in the designs of madrasa buildings.
3- Geometric and sophisticated research in Mamluk buildings design methods open perspectives to elementary issues of architectural design and the shaping process about Islamic architecture in Egypt in general.
4- The reflection of sophisticated geometry on architectural design is an interesting aspect of Islamic architecture, because Islamic science of buildings had reached high standards, both in building design and building construction, and because the architects of traditional Islamic buildings had an extremely highly sophisticated knowledge, both of geometry and mathematics.

9- Research General Consideration

- The vast abundance and diversity of the historic buildings of Islamic architecture present a problem in any generalization of design. To make the task easier, only the buildings that share a commonality in structure have been considered.
- The developed geometric generative technique does not generate all varieties of design that have existed in history, but it is able to generate a wide range of buildings.
- Errors and slight inconsistencies in axes, proportions, and angles have been ignored in order to facilitate a more general wholesome discussion of the generation of design. Wall widths have been ignored for the purposes of this study.
- One of the biggest challenges in the creation of the geometric generative technique is to allow the possibility of generating a variety of designs, while limiting the rules. Moreover, strong constraints and control mechanisms were used to limit the generation of irrational designs.
- As building types of Islamic architecture are fairly variegated, it is not claimed that the technique suggested in this research would create every kind of religious complex building that has existed in history. Rather it is felt that the geometric analysis of complex buildings embodies an approach to a design method based on Islamic principles. Its real scope lies in evolving the geometric principles to give contemporary explanations or interpretations to madrasa design generated in generic configurations, so that valid present-day designs are generated.

10- Research Skeleton

The research is divided into three main parts, as follows:

- **The Introduction:** Research Problem, Objectives, Hypothesis, Questions, Methodology.
- **The Theoretical Part:** Chapter One, Tow, Three and Four.
- **The Analytical Part:** Chapter Five and Six.

Fig. (3) The research skeleton

Design Method

Geometry

Islamic Architecture

Research Skeleton

Introduction

The first part | The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

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Appendix A — A Computer-Aided Generator for Madrasa Buildings Design

1. Chapter One: Literature Review (Geometry and Architecture)

1.1. Introduction

Design is a process, a dynamic interaction between the concept and contingency between the generic and the specific; it evolves progressively as multiple individual decisions are assimilated into the whole [Gelernter,1995]p.49.

Design methods encompass a wide variety of subjects, from describing the design problem to asserting the social and political consequence of the building layouts. A particular issue that lies at the core of design method was focused on in this study: what is the role of geometry in creating the architect's design idea, and what are the geometric relationships between the design vocabularies?. At the beginning of the design process the architect possesses only a random collection of information, requirements, intentions and assumptions, and then suddenly on the drawing board there appears a proposal for a design idea for a building. How is this idea generated? Is geometry an important factor influencing its shape? What is the role of geometry in the process of deriving the design idea? How does its role continues to affect all aspects of the architectural design process?

These are central questions for a design method for a number of reasons. For architects, the key issue at the heart of their practice is the task of developing the design of a building, because during all stages of architectural design geometry has a set of normative principles that could guide the architect's design activities. In needs to be taken into consideration that, the architects did not invent their design methods in a vacuum, but rather inherited them from their cultures.

Geometry is the major factor which shapes the architects' design idea. For many ancient architects, the guidance came from geometry, which functioned as a good tool providing architects with guidance rules (precise geometric system) with which to generate buildings designs. For example, the ancient Egyptian theory of architectural design and design method was seemingly empirical and only minimally indebted to mathematics. The architect employed simultaneously a modular system and a geometric system. The module would be derived from a major dimension in the building under design, the width of the inner room in a temple for example. Multiples and fractions of the module would then determine all the other dimensions of the building, as well as the placement of the columns and piers. The geometric system depended on a few simple figures, mainly the square and a few triangles with specific ratios of base to height. Relying on a set module and combination of two or more of these basic geometric figures, the Egyptian architect prepared a ground plan and a set of outline elevations for all parts of the building in question [Kostof,1977]p.8-9.

The process of architectural design is an intellectual and imagination activity, based on a continuing internal dialogue in the designer's mind about the nature of the design problem which he faces. This dialogue aims to understand all the conditions and dimensions of the design problem components and their impact on one another, and he tries to find a solution that takes all these into account and achieves the goals, objectives and tasks required by the nature of the design problem [Hassan,1997]. The use of geometric systems in architectural design makes it easy for the designer to understand the nature of the design problem, which explains the longevity of the traditional buildings design and explain why almost classical architecture was bound by geometric proportions, and geometric homogeneity was considered an axiom of good design.

1.2. Geometry in Architecture

The Greek civilization was followed by the Roman civilization; Christianity appeared in Roman times; the Roman civilization thus straddled both sides of the Christian calendar: BC and A.D. Following the fall of the Roman Empire there began what are generally known as the Dark Ages, which elapsed from roughly the late fifth to the late 15th century.

In the midst of Europe's darkness, almost immediately after the fall of the Roman Empire, Muslim civilization came into being. It was in the year 622 that the Prophet's Hijra[1] took place. Following the death of the Prophet (pbuh)[2], Islam spread to neighbouring lands, and was rapidly embraced by the various local populations. By 750, the Muslim lands stretched from Spain to the borders of China. Unlike Europe, which was gripped by the darkness, the Muslim scientific revolution took place exactly during the apogee of Islam, from roughly the late 8th century to the 13th century [Zaimeche,2002]p.3, especially the science of geometry, which became a very important tool in the hands of builders for design and construction. Fig. (1-1) shows the position of Islamic architecture in the architecture history timeline.

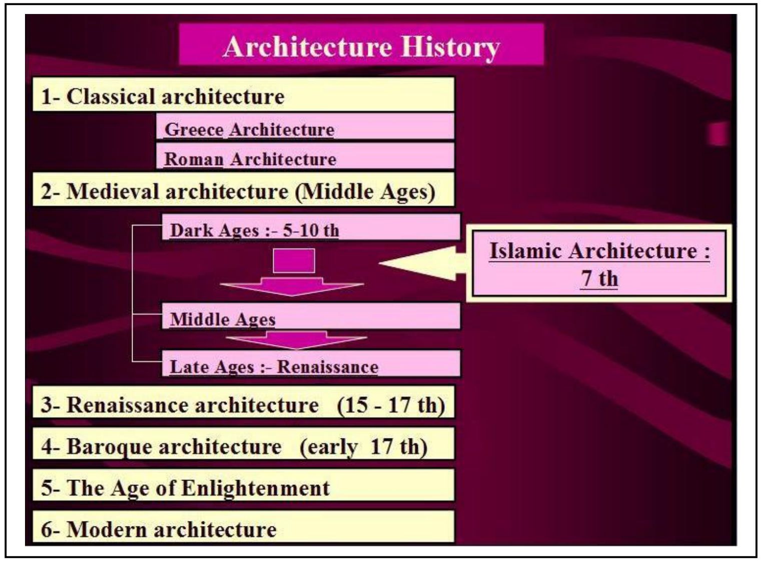


Figure 1-1: The timeline of architecture history

1.2.1. History of Geometry and the Geometry Time Line

Geometry, which comes from the Greek words *geo*, "earth," and *metrein*, "to measure", is a part of mathematics concerned with questions of size, shape, and relative position or spatial relationship of geometric figures and with properties of space. Ancient scientists paid special attention to constructing geometric objects, and the classical tools allowed in geometric constructions are those with compass and straightedge. The mathematician who worked in the field of geometry was called a geometer.

Since geometry was encountered in the first written records of mankind and was developed extensively by ancient Egyptians, Babylonians, and Greeks, one might suppose its discoveries had been exhausted long ago. Not so! The subject is slow to reveal

[1] **The Hijra** is the migration of the Islamic Prophet Muhammad from Makkah to the city of Madinah

[2] **P.b.u.h** means : peace and blessing be upon him. Muslims use these initials after mentioning the name of Prophet Mohammed (p.b.u.h) or any other Prophet to express their love and respect.

its secrets. There are still geometric principles yet to be uncovered and new applications for architecture that can improve the state of the art [Blackwell,1983]preface.

The following table demonstrates the geometry time line and how geometry has been transferred between different civilizations according to Lanius, and also presents the major contributions from each one to the science of geometry.

<table>
<tr><th>Civilization</th><th>Date</th><th>Contributions</th></tr>
<tr><td>Egyptians</td><td>c. 2000 - 500 B.C.</td><td>Ancient Egyptians demonstrated a practical knowledge of geometry through surveying and construction projects. The River Nile overflowed its banks every year, and the river banks would have to be re-surveyed. In the Rhind Papyrus, pi is approximated.</td></tr>
<tr><td>Babylonians</td><td>c. 2000 - 500 B.C.</td><td>Ancient clay tablets reveal that the Babylonians knew the Pythagorean relationships.</td></tr>
<tr><td>Greeks</td><td>c. 750-250 B.C.</td><td>For centuries Ancient Greeks practiced centuries of experimental geometry like Egypt and Babylonia had, and they absorbed the experimental geometry of both cultures.
They created the first formal mathematics of any kind by organizing geometry with rules of logic. Euclid's (400BC) important geometry book The Elements formed the basis for most of the geometry studied in schools ever since.</td></tr>
<tr><td colspan="3">• After the fall of the Greek and Roman civilizations, Europe entered the Dark Ages.</td></tr>
<tr><td colspan="3">• Advances in geometry were made largely by Muslims in the Middle East and North Africa and Hindus in India.</td></tr>
<tr><td colspan="3">• Most of the works of Greek mathematics were scattered or lost. Some of these, including Elements, were translated and studied by the Muslims and Indian.</td></tr>
<tr><td colspan="3">• During the 12th and 13th centuries ‘Elements’ was translated from Greek and Arabic into Latin and the modern European languages, and geometry was added to the curriculum of monastic schools.</td></tr>
<tr><td colspan="3">• The Modern Geometry: Representing geometric figures within a coordinate system. Discovering the link between geometry and algebra. Analytic, projective, and descriptive geometry came into being within the framework of Euclidean geometry.</td></tr>
</table>

Table 1-1: The geometry timeline [Lanius]

1.2.2. The Role of Geometry in Architecture Design

Geometry, according to the Encyclopaedia Britannica, is the study of space and architecture, in the broadest sense of the word, is the creation of space by construction or subdivision. The two disciplines are virtually inseparable with one distinction. Geometry can exist without architecture but architecture cannot exist without geometry. Geometry is not all of architecture but it is an essential part of it [Blackwell,1983]p.3.

Architecture and Geometry are virtually inseparable. Architecture and geometry together form a powerful union of creativity; one is the instrument for the other. Geometry creates the balance between the imagination and exacting realism in architectural work. It also helps the architect understand the properties and relationships of lines, patterns, surfaces, and solids. This understanding is almost as essential to an architect as breathing, regardless of whether one is designing a coffee table or a fifty-story building. So geometry is everywhere in architecture; at the same time, without architecture, geometry would be a "dead language". Architectural space must serve the needs of humans with some exactness: floors must be levelled, stairs must be straightened, buildings must be buildable, and there are always functional requirements and conditions in the arrangement of architectural space [Blackwell,1983]p.49. Geometry is the secret effective factor which helps architects make the architecture of the building suit its purpose besides fulfilling the required human needs. So a successful architectural space design depends on clear spatial arrangements. In this regard, the geometrical harmony between different forms and shapes used for different functions in the building is an essential part of an effective design.

Architects in ancient cultures believed that, architectural geometries could be enjoyed both intellectually and sensually. The guidance for many ancient architects came from geometry. Perhaps based on the belief that orderly geometry reflects the order of the divine world, they established precise geometric systems with which to generate forms [Gelernter,1995]p.40. So they aimed to capture the best sequence of geometric operations underlying the generation of the building design. For example if a diagram was used to design a building, the important and main space was located and then geometry came into play to offer a means of organizing vistas and privileged lines of sight. Architects in almost ancient cultures desired to base their design on timeless principles behind appearance. Therefore, they wished to base architectural design on more than the contingencies of a particular site, climate or individual designer. Much of their efforts attempted to set out the 'fundamental principles of architecture' and obtain the timeless characteristic of design which would help practising architects achieve a universal validity and beauty in their work [Gelernter,1995]p.62. So, almost ancient architects' attempts tried to capture the underlying principles of design and discover the true principles of timeless design.

1.3. Theory and Principles of Design in Islamic Architecture

Islamic architecture exists because of the existence of Islam, and by many ways it serves the essence of Islam. Therefore, it can be seen as a special kind of architecture, as a cultural phenomenon determined by special qualities inherent in Islamic legislations. For this reason it encompasses a wide range of both secular and religious styles influencing the design and construction of buildings. The process of building design is not only concerned with the form of buildings but also of equal importance are all the phases and aspects of design. It is almost impossible to identify one phase or aspect in the design process and consider it more important than others. This means that there are no strict rules applied to governing Islamic architecture. The architects used local geometry, local materials, local building methods to express in their own ways the order and unity of Islamic architecture. According to that, when the religious monuments of Islamic architecture examined they reveal complex geometric relationships and great depths of symbolic meaning.

1.3.1. Definition of Islamic Architecture

Much has been written and said about the meaning of Islamic architecture. In order to understand the definition of Islamic architecture, there are two distinctive questions that must be taken into account. The first question is if Islamic architecture is the architecture produced for and by Muslims to serve Islam as a religion or one which serves a religious function - the mosque, the tomb, the madrasa. The second question is whether all the architecture is produced in Muslim Lands. Generally Islamic architecture is a style of architecture that does not change its forms easily, if at all, according to functional demands, but rather tends to adapt its functions to preconceived forms, which are basically the contained internal spaces [Grube,1995]p.12-13. So the research attempts to carry out an analysis of the manner in which these internal spaces are defined and articulated, because this should provide us with additional information concerning the specific quality of this architecture.

Islamic architecture means the architecture of Muslims, regardless of time or place that reflects Islamic values. It is directed by Islamic teachings and doctrine from the Holy Quran, the Sunnah[3] and in its form expresses the spirit of Islam [Omar,2000]p.8.1. In other words, Islamic architecture is a container of the beliefs, systems, principles, teachings and values of Islam.

Islamic architecture is a style of architecture whose functions and forms, are inspired primarily by Islam. Practically, Islamic architecture represents the religion of Islam that has been translated into reality by the hands of Muslims. It also represents the identity of Islamic culture and civilization [Omer,2009]. This means that it is a framework for the implementation of Islam legislation. Islamic architecture can only come into existence under the aegis of the Islamic perceptions of God, man, nature, life, death and the hereafter, so its main purpose is to facilitate the worship activities of Muslims, which accounts for every moment of their earthly lives. Thus, Islamic architecture would be the facilities and, at the same time, a physical locus of the actualization of the Islamic message.

1.3.2. Islamic Architecture Design Theory

There is no fixed design theory in Islamic architecture, but there is a fixed content of Islamic architecture. In order to understand that, the Islamic approach to architectural design is explained; the Islamic content in architectural design is demonstrated by determining the sources for the Islamic architectural content, and explaining how this Islamic content controls

[3] Sunnah (plural Sunan) is an Arabic word that means habit or usual practice. The Muslim usage of this term refers to the sayings and living habits of the Prophet Muhammad. The Sunnah of the Prophet Muhammad includes his specific words, sayings, habits, practices, acts, acceptances, and silent approvals.

the architecture design process, and how it is transferred from one generation to the next through the long ages of Islamic architecture. Finally, the fixed Islamic principles for architecture design are presented. All these aspects explain why Islamic architecture is unified despite the long distances that separate the Arab states.

1.3.2.1. Islamic Approach in Architecture Design

Building legislation is part of a law that had been developed since the advent of the religion of Islam. The main reference books are The Holy Quran and the Sunnah. During the first century of Hijra several Muslim scholars collected the Sunnah from the Prophet’s companions and followers who were spread all over Muslim world. These were several approved written books of Sunnah, containing several thousand Prophetic traditions related to Muslim life, law, and advice including general rules on planning and building. These rules were documented in several books of Fiqh[4], known to almost every Muslim, which include every single matter relating to Muslim life. These books of Fiqh include building and planning legislation and the responsibilities of individuals and the authority in this law. The legislations had to develop Islamic Law to include new materials within the framework of Islam. Whilst building legislation is a part of Fiqh, it is surprising that there are several books for building legislation only; some of them are still in a manuscript form, others have recently been investigated and written by researchers [Hammad,1997].

The approach to architecture design in Islamic architecture depends mainly on Quran and Sunnah of the Prophet Muhammad (p.b.u.h.). They contain a fixed Islamic content and fixed rules on building and planning, from which the Muslim architect can extract and derive design basic principles, design fundamental idea, design rules and design values. This content and rules are transferred to different generations and between different places during the long ages of Islamic architecture with the Quran texts and the Prophet Sunnah, Fig. (1-2) shows the Islamic approach in architecture design.

[4] Fiqh is Islamic jurisprudence (the explanation of Sunnah). Fiqh is based directly on the Quran and Sunnah. Fiqh deals with the observance of rituals, morals and social legislation in Islam. There are four prominent schools of fiqh, the Madh'hab (Maliki, Hanafi, Shafi'i, and Hanbali Madh'hab). A person trained in fiqh is known as a Faqih (plural Fuqaha).

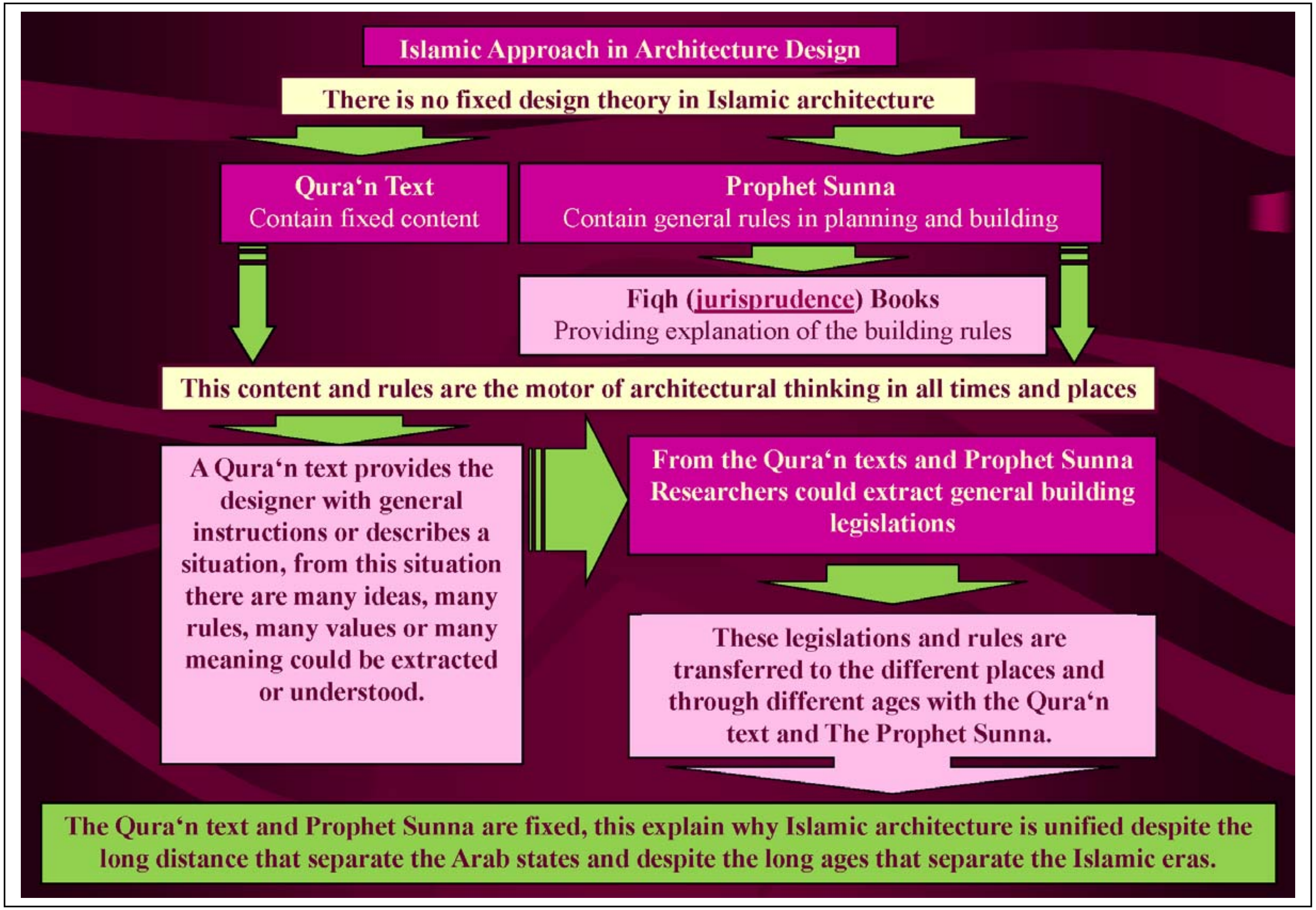


Figure 1-2: The Islamic approach in architecture design[5]

[5] For more details see, Tomy Isma'il, ***Al'aimarah wa al-'aimaran fi Zilala al-Quran*****,** Chapter 2 describes how to extract the building legislations from the Quran text.

1.3.2.2. The Islamic Context (Content) of the Architecture

The 'context' as a scientific term is more universal and comprehensive than 'function' which is governed by engineering, technical and economical determinates aiming at achieving the best utilization of space. Function in architectural action, while context is an expression that includes the functional, together with the social and human needs. In Islamic architecture the context is related to Islamic values and instructions that should be provided in different building types [‘Abdel-Baqĩ Ibrãhĩm,1986]p.78.

The Islamic context an expression that combines the functional and convictional aspects, is considered the basic approach to the Islamic perspective of architecture. It is afterwards finished off with formal values related to the local environmental cultural and historical background of the place. The context is thus the constant (universal) aspect of the Islamic perspective of architecture, while the form is the variable (local) aspect. The Islamic context of architecture is directly or comparatively related to Quran instructions and the Sunnah of the Prophet (p.u.b.h.). The Islamic context in the first place, determines the forms and spaces composing the architectural work and organizes the functional relations between them, then comes the artistic expression through local building material and methods, in addition to the technical and cultural inherited values of the society, which do not contradict with the Islamic content. In other words, we can say that Muslim’s architecture is considered a local architecture based upon Islamic values.[(OICC),1992]p.486.

Quran and Hadith are the main sources of legislation and religion, and from them the design contents for architecture can be extracted or derived. This content represents the design rules transferred from one generation to the next with Quran texts, and because of the fixation of the Quran texts it can be understood why Islamic architecture is unified despite the long periods that separate the different Islamic eras.

Thus, Muslim architects should be obligated to the Quran and the Sunnah of the Prophet Muhammad (p.b.u.h.) since they are the main sources which determine the fundamentals ideas and basic principles of the Islamic society’s architecture. This leads them to the understanding of the Islamic design contents of various types of public and private buildings before starting with the building design. From this design perspective it is found that the main feature of Muslim architecture is it’s affection with the law of Islam (Shari‘ah) and the Sunnah of the Prophet Muhammad (p.b.u.h.).

1.3.2.3. Islamic Principles in Architecture Design

Islamic principles in architecture design are a very big theme containing many aspects. There are many scholars who have written about this subject, so some of the Islamic principles in architecture design which are related to the research topic and focus mainly on the role of geometry in architecture design in Islamic architecture, are presented.

1- <u>The Principle of Unity in Islamic Architecture</u>

When one walks through the remnants parts of any traditional Islamic city - whatever the difference of natural environment or climate - what is immediately apparent is its Islamic identity, this tangible identity depends not upon uniformity of design or materials but upon the fundamental unity of the traditional society that lived in these cities according to traditional principles [Al-Wakĩl,1984]p.26. There is no doubt that there has been change and development of forms during different Islamic eras; but more importantly, there has always been continuity with unity.

Islamic architecture was characterized by diversification in the composition while maintaining the unity in architectural formal configurations. For every types of building there is a set of diverse design patterns that governs its design and determines its main features. These design patterns share a determined and unified general content. For example, in the complex buildings the Muslim architects used the open courtyard as a basic unit in the design. The courtyard played the role of the backbone and all the rest of the building's spaces surrounded it in consistency and coherence. Beside the unity in plan design, Islamic architecture was characterized also by the diversification in the building configuration. The Muslim architects used the dome, vaults and flat roof in the same building but all had been interconnected through a single formal language, based on geometric relationships which had been based on the idea of unity and opening to inside.

The architecture of the Islamic world throughout history had adapted and responded to different cultures and existing traditions of buildings without weakening the spiritual essence which was its source of inspiration. Urban centres in Islamic cities evolved over long periods of time with generations of craftsmen whose sensitivity and experience added variety and a diversity of styles to the environment. The traditional Islamic city reflected a unity which related the architecture of the mosque, the madrasaa, the souq, palace and the home as a sequence of spaces [(IAAO),2004]. The concept of unity in multiplicity is the determining factor in integrating Mamluk architecture compositions. The identity of the Mamluk composition lay in the geometric relationship of its elements. These relationships generates the harmonizing between the composition and the forces acting on it (for example the building site restricts, the patron demands on his building, the messages which the architect want to saying it behind his design and the symbolic meanings which he want to present it to the building users), that enabled the interaction of building design and methods to evolve an Islamic identity, in the same way a language maintains its own identity even when it absorbs outside words.

2- <u>Designing From Inside to Outside</u>

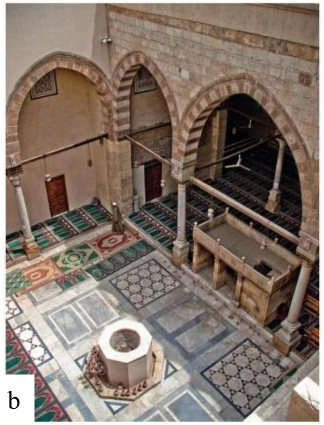
The architecture design process of Islamic buildings is a process that has one direction: starting with the function and ending with the form and is mainly concerned with the function (in its broad sense), rather than the form which envelops it. This means that the designing of almost types of buildings in Islamic architecture begins inside (function) - out (form). For example, in the design of complex buildings which articulates around the inner courtyard, the design starts from the position of the courtyard and according to it the position of the other spaces are located, with regard to the functional relationships between the different spaces[6].

3- Concentration on the Interior (Introvert Design)

Islam is a religion concerned with and is interested in the inner essence before the external appearance, so in Islamic architecture the obvious interest with the inner architecture more than the outside forming or shaping architecture is noted. The interest does not stop till the internal forming but includes also the internal function relationship between the building's different spaces. The more success in design process there is the more attention to obtaining the required functions relationships in the design idea there is.

One of the most striking features of all Islamic architectural monuments is their focus on the enclosed space. The design of two types of buildings - religious and complex - depends on organizing or articulating the main spaces and the total design around an inner courtyard. The transition from the bent entrance to the courtyard through the narrow passage is one from subdued darkness to bright sunlight [Antoniou,1998]p.107. The courtyard is used as the heart of the building as shown in Fig. (1-3). The internal courtyard replaces the external environment and includes various activities for the users. This does not mean that the outside appearance of a structure is disregarded, but it obtains also a high degree of importance, especially in monumental structure, such as the congregational mosque or the complex buildings.


a


b

c

Figure 1-3: Concentration on the interior in Islamic religious buildings
a- Mosque of Ahmed Ibn Tulun
b- Mosque of Shayku
c- Complex of Sultan Barquq

[6] Chapter 4 will explain in detail how the Mamluk architects used geometric principles (as starting from inside at the centre point and continues outside) to generate the whole Madrasa building design.

4- Homogeneous Architectural Form

Homogeneous in the architectural form was one of the main features of the architectural expression, especially in the facades of public buildings in Islamic architecture. Homogeneity appears in the facades of complex buildings to reflect a continuous movement between a group of horizontal levels, constituting its various elements through an irregular rhythm. Although the Muslim architect used different types of architectural shapes in the same building, all of them are homogenous with one another. Fig. (1-4a) shows how the Muslim architect could use the dome, vault and flat roof in the same building in a homogeneous geometric composition, but Fig. (1-4b) shows the geometric homogeneity between the elevation components and also in the building form composition.

Figure 1-4: The geometrical homogeneous in the architectural form
a- Madrasa of Amir Sarghatmish, b- Complex of Sultan Qaytbay

5- Using Geometric Pattern

In the measurement and geometric analysis of an ancient structure, it is often necessary to combine scientific and mathematical objectivity with an open mind that permits an understanding of what appears to be the intentions of the design [Reynolds,1999]p.23. In Islamic architecture, it was geometry that provided diverse stylistic developments for constructions and designs; not only to serve a function, but also to evoke the harmonization of the constructional elements form, such as domes, columns, and decorative elements.

The mathematicians and architects during Islamic eras transferred geometry into the art of architecture. The sophisticated geometry involved in interior decorations shows how architects tried to express their beliefs and philosophy, through complex geometric designs involving repetition, rhythm, pacing, scale, and color combination. The construction of domes shows that they were also aware of the geometry of 3-dimensional Euclidean space. The designs reveal, through self-similarity, and using self similarity in decoration geometric patterns design that the artists had a sense of fractal geometry. Fig. (1-5) shows the geometric patterns used in a dome decoration of the Sultan Qaytbay complex.

The Muslim architect used Islamic content as his mentor and geometry as his tool in developing architecture during different Islamic eras. He used geometry as a formative idea with the concepts of plane and solid geometry determining the built form, in the process of space and form design he depended on the basic geometric shapes, for example he used the square, rectangle, octagon, triangle, hexagon, circle and arc, because they allow an ordering of space that encompasses both composition and construction. Besides basic geometry, he used geometric processes as combinations, multiples, derivatives, and manipulations.

The Muslim architects used proportion, pattern and hierarchy in all of their work as well, which are keys to the consistent and systematic quality underlying all of a Muslim architect's work.

Figure 1-5: Geometric patterns cover the dome surface in Madrasa of Sultan Qaytbay

6- Fulfilling Muslims' Architectural Needs

Islamic architecture in its broad sense responds to meeting the needs of Muslims. Every early Muslim designer was guided by the teachings and legislations of Islam, so the building design came under the umbrella of Islamic traditions and teachings. In different Islamic eras, the role of architects was to understand the lessons of tradition without copying historic forms. Designing the buildings was done with the full consideration of their Islamic function and insight of the legislation framework to fulfill Islamic identity and reach Islamic values in architecture.

All these principles besides many others, such as the symbolism in architecture, which some scholars refer to as a main goal and main factor affecting the architects' thinking during many Islamic eras, were used by the Muslim architect in his design process and most of which are extracted mainly from the Quran and Sunna.

1.4. The Role of Geometry in Islamic Architecture

The role of geometry in Islamic architecture is discussed in regard to two points. The first explains the contributions which were made by early Muslim scholars to the science of geometry and the second demonstrates how the Muslim architect used geometry in the process of building architecture design during different Islamic eras, and how geometry affected and helped architects in generating their design idea.

1.4.1. The Greatest Scientific Contribution Muslims Made to the World

The 7th to the 13th century marked was the golden age of Muslim learning. The following table displays Muslims' contributions to different branches of science on which the early Muslim architects depended in the architectural design and construction of complex religious buildings.

science	Muslims Contributions
Mathematics	They invented the arithmetical decimal system and the fundamental operations connected with it addition, subtraction, multiplication, division, and extracting the root.
Arithmetic	They introduced the 'zero' concept to the world. This led to the creation of mathematical science. Algebra, geometry, algorithm and arithmetic.
Spherical Geometry	Muslims developed spherical geometry in order to : * Find the direction to Mecca (Qibla) and orient the mosques in that direction. * Find the time of prayers, Muslims need to determine the proper times for the prayers at sunrise, at midday, in the afternoon, at sunset, and in the evening.
Astronomy	In order to observe holy days on the Islamic calendar in which timings were determined by the phase of the moon Islamic months do not begin at the astronomical new moon, defined as the time when the moon has the same celestial longitude as the sun and is therefore invisible; instead they begin when the thin crescent moon is first sighted in the western evening sky. So that this led Muslims to find the phases of the moon in the sky, and their efforts led to new mathematical calculations.

Table 1-2: The greatest scientific contribution Muslims made to the world

1.4.2. Famous Muslim Mathematicians and Geometers

Historically, architecture was part of mathematics, and in many periods of the past, the two disciplines were indistinguishable. In the ancient world, architects were mathematicians who built the constructions [Sagdic,2000]. Some Muslim mathematicians and geometers, who made great contributions to the science of geometry and accordingly to architectural science, are mentioned below:

1- Al-Khowarizmi (780 - 850 CE) (mathematician).

Muhammad Ibn Musa Al-Khowarizmi, the father of Algebra, was a mathematician and astronomer. Algebra (Al-Jabr) derived its name from the title of his work, Hisab Al-Jabr wal Muqabalah (Book of Calculations, Restoration and Reduction). It is believed that this book of Al-Khowarizmi's arithmetic text was translated into Latin in the 12th century by an English scholar and mathematicians used it all over the world until the 16th century. Al-Khowarizmi left his name in the history of mathematics in the form of Algorism (the old name for arithmetic). Al-Khowarizmi emphasized the fact that he wrote his algebra book to serve the practical needs of the people concerning matters of inheritance, legacies, partition, lawsuits and commerce.

2- Al-Kindi (801-873 CE) (philosopher, mathematician, physicist, astronomer and physician).

Abu Yusuf Yaqub Ibn Ishaq Al-Kindi, was born in Kufa during the governorship of his father. To his people he became known as Faylasuf Al-Arab (the philosopher of the Arabs), the first in Islam. Among his contributions to arithmetic, Al-Kindi wrote eleven texts on numbers and numerical analysis. In mathematics, he wrote four books on the number system and laid the foundation for a large part of modern arithmetic. He was a prolific writer and altogether wrote 241 books, divided as follows:-

Table 1-3: Al-Kindi types of books

Branch	Number of books	Branch	Number of books	Branch	Number of books
Astronomy	16	Medicine	22	Logic	9
Arithmetic	11	Physics	12	Psychology	5
Geometry	**32**	Philosophy	22	Music	7

3- Al-Battani (850-929 CE) (astronomer, mathematician and astrologer).

He is the father of trigonometry, and considered to be the greatest Muslim astronomer and mathematician. He computed the first table of cotangents. He made a number of important discoveries, including the accurate determination of the solar year as

365 days, 5 hours, 46 minutes, and 24 seconds, which is very close to modern estimates. He also determined with accuracy the obliquity of the ecliptic, the length of the seasons and the true and mean orbit of the sun.

He wrote a number of books on astronomy and trigonometry. His most famous book was his astronomical treatise with tables which was translated into Latin in the 12th century. This was extremely influential in Europe until the Renaissance, with translations available in several languages. His original discoveries in both astronomy and trigonometry were of great consequence in the development of those sciences [Ahmed,1997].

4- Abu al-Wafa Al-Buzjani (940-998 CE) (mathematician and astronomer).

In geometry his contribution comprises a solution to geometric problems with the opening of the compass. He explained the links between number theory and geometry. He wrote two famous books. The first one is “On the Geometric Constructions Necessary for the Artisan”, in which he described several constructions made with the aid of straightedge and “rusty compass”, a compass with a fixed angle [Özdural,2000]. The second one was “Kitab al-Handsa” (Applied Geometry), in which he discussed many aspects of Applied Geometry.

In the field of astronomy he discussed different movements of the moon, and discovered 'variation', in order to solve difficult problems in Islamic Astronomy (to predict the first visibility of the moon, it was necessary to describe its motion with respect to the horizon, and this problem demands fairly sophisticated Spherical Geometry)

5- Thabit Ibn Qurra (836-901 CE) (astronomer, geometer, and anatomist).

In the domain of geometry he wrote his book “Composition of Ratios”. In this book he dealt with arithmetical operations applied to ratios of geometric quantities. By introducing arithmetical operations on geometric quantities he started a trend which led, eventually, to the generalization of the number concept.

6- Al- Bayruni (973-1050 CE) (astronomer and mathematician).

Al-Bayruni was among those who laid the foundations of modern trigonometry. He was a philosopher, geographer, astronomer, physicist and mathematician. Six hundred years before Galgeo, Al-Bayruni discussed the theory of the earth rotating about its own axis. Al-Bayruni carried out geodesic measurements and determined the earth's circumference in a most ingenious way. With the aid of mathematics, he enabled the direction of the qibla to be determined from anywhere in the world.

1.4.3. The Role of Geometry in Islamic Religious Architecture

The role of geometry did not stop at the building design in Islamic architecture; it extended to building decoration and ornamentation. How Muslim architects could use the geometry as a great benefit tool in building design and building decoration is discussed as follows.

1.4.3.1. The Role of Geometry in the Architectural Design of Religious Buildings.

During different Islamic eras architects depended on pure geometric shapes for the building design, such as squares, rectangles and circles, as the main unit in the building plan design, and then through a series of prescribed steps (these steps demonstrate the geometric relations between these shapes) they generated complex geometric form that organized the building in section and in plan (organizing the building spaces in three dimensions composition).

To understand the role of geometry in Islamic architecture design, a geometric analysis for three historical buildings is introduced. The objective of this is to search for the fundamental geometric principles of their architectural composition. By means of geometric analysis it is possible to find a proportional key, which indicates how the elements are arranged in the work of architecture design, and what roles they have. The advantage of demonstrating the geometric analysis is to provide architects with an explicit or clear method not only for the understanding of architectural composition of sophisticated design, but also to give architects insight into the construction of a new design idea by using geometrical schemes. The three buildings are as follows:

1- The Use of the Golden Section in the Great Mosque at Kairouan, Tunisia 670 A.D.

The mosque is composed of two parts: the court and the prayer space. The dimensions of this space are less than that of the court. It has seventeen naves perpendicular to the qibla wall. The axial aisle and the one parallel to the Qibla wall are larger than the others, forming a T-shaped plan. The minaret is the dominating feature in this composition. Its elevation is divided into three levels. The mosque has an irregular plan. It forms nearly a rectangle, with its four sides not perfectly parallel. Only the eastern side has a good alignment. This deformation is due to site conditions.

Taking into account the fact that many traditional buildings have used the golden section, it has to be mentioned that the golden section is used as a proportioning system in this mosque. The following figures show the use of the golden section in determining the dimensions of the plan and the height of the minaret [Boussora and Mazouz,2004]p.12-15. This investigation and the following figures presents to us that there are hidden geometric principles used in this building design, which lead us to think about the progress of the science of geometry and how it reflected on the design of the traditional Islamic complex buildings during different Islamic eras.

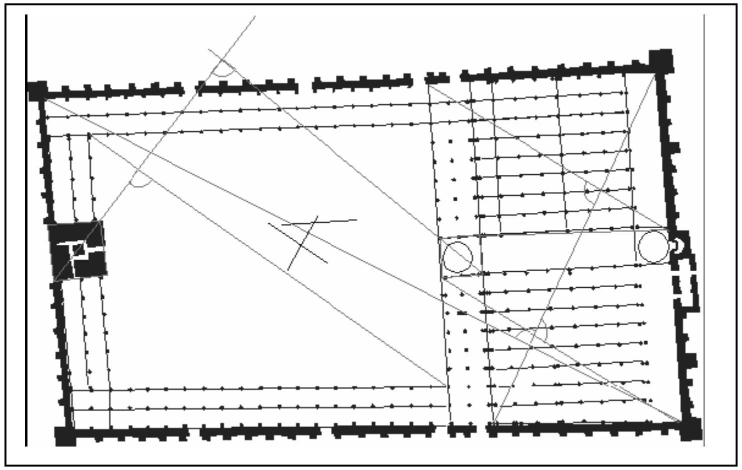


Figure 1-6: The existence of regulating lines in the Great Mosque at Kairouan

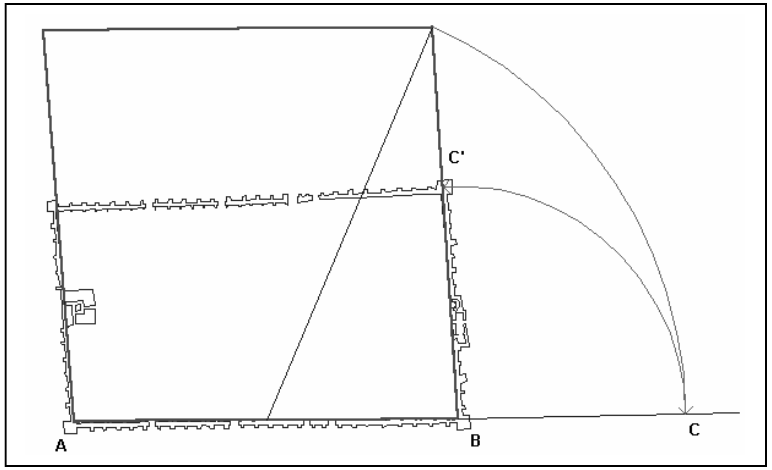


Figure 1-7: The dimensions of the plan expresses the use of the the golden section in the Great Mosque at Kairouan

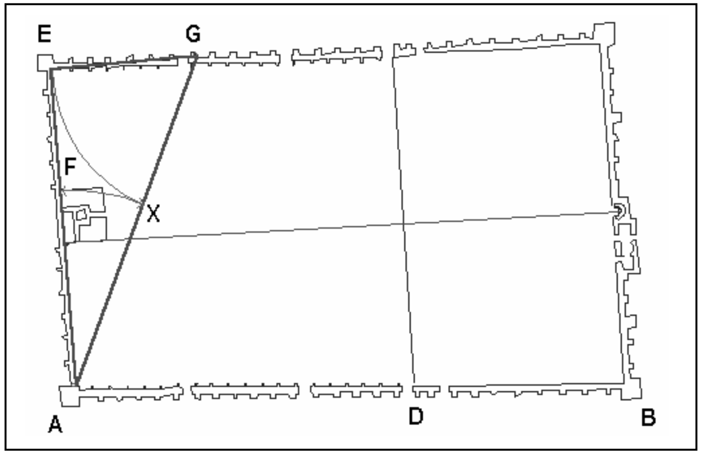


Figure 1-9: The geometric construction of the minaret in the Great Mosque at Kairouan

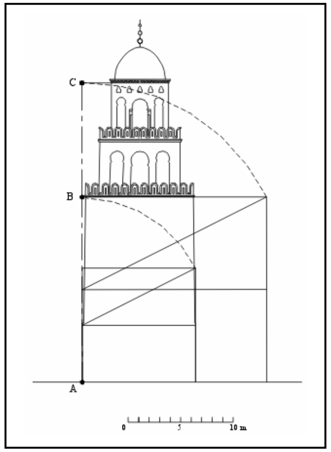


Figure 1-8: The geometric order used in determining the height of the minaret in the Great Mosque at Kairouan

2- The Use of the Geometric Concept of Three Intersecting Circles in the Great Mosque of Cordoba, Spain 785A.D.

The great mosque was built around 785 A.D. in Cordoba, Spain. The building has many elements belonging to various different periods and, as a whole, was subjected from the late 8th to the late 10th century to a total of five extensions [Fazio*, et al.*,2004]p.171, one merging with another with no apparent break line. The architectural concept has been allowed to grow and multiply for two hundred years, so that the later structure would still relate to the original principle

In the Great Mosque of Cordoba, strong geometric principles, based on the harmonic subdivisions of a squared circle in which the alternate sides relate in 1:2 proportions, appear to underline its architectural planning. The layout of the mosque is unique; it is neither a square nor a rectangle, which can be easily explained.

The following figure shows the geometric concept of three intersecting circles, encompassing perfectly the periods of the mosque's extensions [Gedal,2002]p.30.

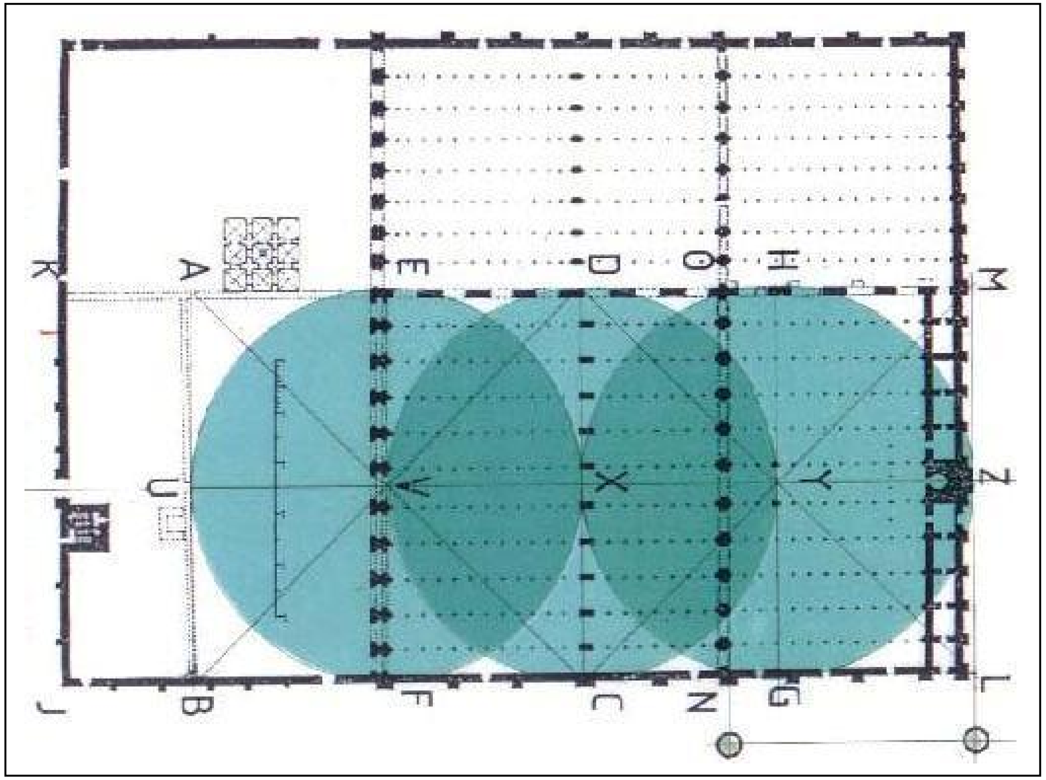


Figure 1-10: The geometrical analysis of the Great Mosque of Cordoba

3- The Use of the Geometric Principles of Design in the Mosque of Ahmed Ibn Tulun, Egypt 876 A.D.

The mosque consists of a central courtyard surrounded with four iwans. The biggest of them is the qibla iwan. There are three exceeding parts in three directions, excluding the qibla wall.

The mosque plan is a rectangle and after adding the exceeding areas it becomes a square (162x162 m). The proportion of the courtyard area to the total area of the mosque is 1:2. The geometric design of the building depended on using the square as the basic unit of design. The following figures show the geometric analysis of the building plan [Mustafa,1993].

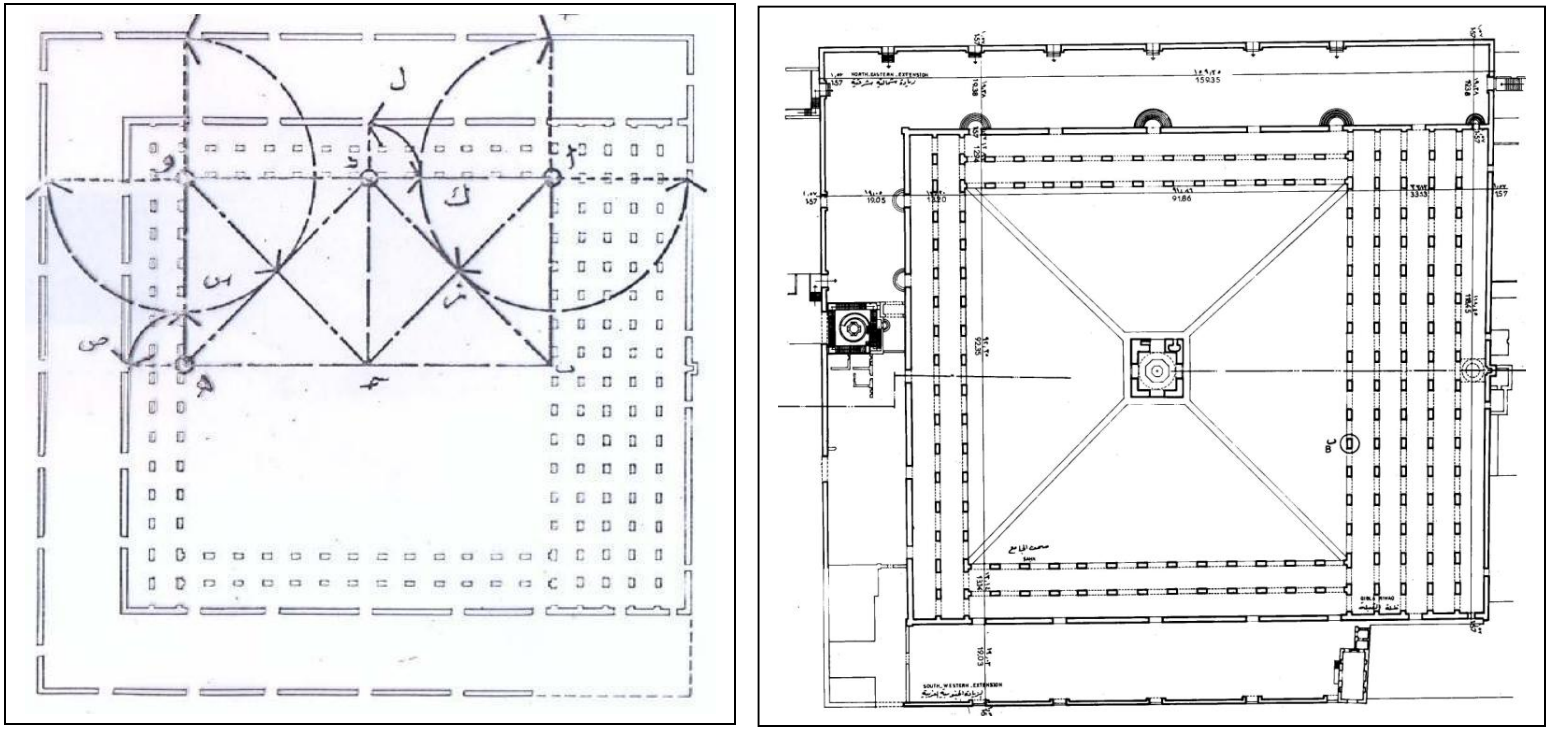


Figure 1-11: The plan for Ahmed Ibn Tulun mosque in Cairo and it’s geometrical analysis

1.4.3.2. The Role of Geometry in Islamic Geometric Ornaments in 14th and 15th Century

Many different techniques of geometric construction have been used throughout the Islamic world, adding practical aids such as squares, stencils and grids to the fundamental tools of compass and the straight edge [Sutton,2007]p.4. Many scholars from both, the Arab and western worlds have tried to discover the design methods which the early Muslim architects used to put the design of their decoration into geometric patterns, and all their focus of intention has been on discovering the underlying geometric order in these patterns designs.

Throughout their long history the craft tradition of the Islamic world evolved a multitude of styles applied to a great variety of media, but always with unifying factors that make them instantly recognizable. It is perhaps no surprise that an art form that seeks explicitly to explore the relationship between unity and multiplicity should be at the same time unified yet diverse. The art of pure ornament revolves around two poles: geometric pattern, the harmonic and symmetrical subdivision of the plan giving rise to intricately interwoven design that speak of infinity and the omnipresent centre; and idealized plant from arabesque, spiraling tendrils, leaves, buds and flower embodying organic life and rhythm [Sutton,2007]p.1. There are three principle areas of Islamic two-dimensional artistic expression: calligraphy, the floral, and geometric patterns, as shown in Fig. (1-12a, b, c). The research concentrates on the geometric patterns, exploring their structure.

Figure 1-12: Islamic artistic two-Dimensional expression

a- Calligraphy **b- Floral Design** **c- Geometric pattern**

Researchers have tried to discover the geometric order which govern Islamic decoration design throughout history. They introduced many methods which demonstrate how the decoration pattern can be generated by using geometric rules and principles, organized in certain steps. All these steps were governed with a clear geometric order.

Only the methods which depend on the geometric principles are demonstrated, through presenting the steps which the researcher follows to generate the decorative pattern. The following methods are presented[7]:

1- Abu'l-Wafā al-Buzdjāni, the geometry needed by craftsmen, (ca. 940–998) [Tennant,2003]p.460.
2- E. Hanbury Hankin's "polygons-in-contact" technique, 1925 [Hankin,1925].
4- Isam El Said, "Compass and Ruler Method", 1962 [El-Said and Parman,1976].
5- A.K. Dewdney "The Over Under Rule", 1993 [Dewdney,1993].
6- A. Aljamali, "Normalization and exploration design method", 2003 [Aljamali and Banissi,2003].
7- Eric Broug, "Step-by-Step" guidance method, 2008 [Broug,2008].

In all of the methods presented in the following, a hidden geometric order is found that plays the role of the secret factor which controls the pattern design

1- <u>Method 1: Abu'l-Wafā al-Buzdjāni (ca. 940–998).</u>

He was one of a long line of Islamic mathematicians who developed geometric techniques that proved useful to artisans in creating the highly symmetrical ornamentation found in architecture around the world today. He showed that **mathematicians** taught **geometry** to **artisans** by means of **cut-and-paste methods** and of geometric figures that had the potential of being used for ornamental purposes. He described several constructions made with the aid of a straightedge and "rusty compass", a compass with a fixed angle.

Method Notion:

1- Constructing a perpendicular at the end point of a line segment.
2- Dividing segments in equal parts and bisecting angles.
3- Constructing a square in a circle and constructing a regular pentagon.
4- These constructions form the basis for creating many of the symmetric patterns of all artisans at that time.

2- <u>Method 2: E. Hanbury Hankin's "polygons-in-contact" technique, 1925.</u>

This method is used for constructing designs based on the following notion:

"In making such patterns, it is first necessary to cover the surface to be decorated with a network consisting of polygons in contact. Then through the centre of each side of each polygon two lines are drawn. These lines cross each other like a letter X and are continued till they meet other lines of similar origin. This completes the pattern."

3- <u>Method 3: Isam El Said, "Compass and Ruler Method", 1962.</u>

This method is used for constructing designs based on the following notions:

1- The understanding of the complete design can be achieved through understanding the significance of the small part and its role in the complete design.
2- The traditional craftsmen would not calculate angles in order to make their compositions.

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[7] Examples demonstrates how these methods can generate the geometric decoration pattern will be present in details in chapter 4.

3- Their tools were a compass and a ruler. With these tools they drew circles and lines and, by connecting intersections of these circles and lines, they created patterns.

4- From a circle it is possible to generate any regular polygon once the circumference has been divided equally to the required number of parts and the points of division are joined with straight lines. The first step of dividing the circumference into three, four and five equal parts or their multiples, determines the subsequent grid pattern(s) and repeat unit, while the radius or diameter of the circle can be taken as a unit measure.

4- **Method 4: A.K. Dewdney "The Over Under Rule", 1993.**

This method is used for constructing designs based on Reflecting Lines through a Regular Arrangement of Circles.

There are four possible symmetry operations that can be done on a plane imprinted with a pattern. These symmetry operations are as follows: translations, reflection, rotation, a glide reflection (translation followed by reflection).

5- **Method 5: Aljamali, "Normalization and exploration design method", 2003.**

This method is used to design and explore Islamic Geometric Patterns (IGP) based on normalization (formulation) of the sub-motif grid (the smallest portion of the symmetrical unit pattern) within the unit patterns that literally hold the entire form of the unit pattern.

6- **Method 6: Eric Broug, "Step-by-Step" guidance, 2008.**

Method Notion:

Every one of the Islamic geometric patterns have its own hidden geometric order, so the hidden geometric order which controls the pattern design is different from place to place all over the Islamic world. The Mamluk architect went on step-by-step to generate his decoration pattern.

1.5. Conclusion

The important characteristics of Islamic architecture are its continuity, variety and unity based on the accumulation of layers of understanding, one on top of the other, such as utilitarian, climatic, social, aesthetic, symbolic, spiritual, cosmological,…etc. to form a wealthy and endless source of knowledge [Gabr,1992]p.6. It is obvious that these traditional Islamic buildings have geometric steps in every design step, so the research tries to blow away the dust from above the layer of geometry in Mamluk architecture, in order to present the important role of geometry in Mamluk architecture in general and make the madrasa building design more understandable in particular. The most concern for this research is making this layer more clear and understandable besides asserting that these geometric models remain the backbone of the process of "designing" of Mamluk religious buildings.

Abdel-Halim Ibrahim, an Egyptian contemporary scholar largely interested in traditional Muslim architecture as a means of re-creating the Egyptian lost identity, explained that there is a layer between the world as it exists and the world as it is shaped by man: this is the layer of creation. He argued that this layer is coded historically through what he called the "creative process of the traditional community", and that each community has its own way and process of its coding and decoding ['Abdel-Halĩm Ibrãhĩm,1989]p.236. Of practical importance to this thesis, he said that although the Islamic tradition is mostly dead in Egypt, the buildings produced by that society (in which were encoded the hidden geometry) still survive, and it is beyond their external composition and forms that lie their qualitative geometric principles which need unveiling. This research started a process of geometric decoding for Mamluk madrasas beginning with understanding the geometric methodology of design behind their architecture composition.

There are hidden geometric principles that govern the decoration patterns design in Islamic religious buildings. The question which presents itself is "are there similar geometric principles governing the process of architecture design for these traditional Islamic buildings in general and madrasa buildings in the Mamluk era in particular?" The research attempts to explore the formal and geometric intentions behind the design of some Mamluk madrasa structures. However, in most circumstances the overriding concern is to explain the role played by the geometry in architectural design process.

This chapter drew the literary background, beginning with demonstrating the relation between the geometry and architecture by concentrating on the role of geometry in architecture design, followed by the demonstration of the theory and design principles in Islamic architecture and demonstrating on the role of geometry in Islamic architecture in the different eras by presenting how the early Muslim architect could use geometric principles as a hidden layer guide the progress of his architectural design. At the end this chapter an attempt has been made to present the conclusion which the research extracted from studying the role of geometry in architecture in general and in Islamic architecture specifically. The next chapter concentrates on the Mamluk religious architecture and then go to demonstrate the role of geometry in the design of madrasa buildings.

Design Method

Geometry

Islamic Architecture

Research Skeleton

Introduction

The first part — The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part — The Analytical Study and the Field Study

Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A — A Computer-Aided Generator for Madrasa Buildings Design

2. Chapter Two: Mamluk Religious Architecture

2.1. Introduction

When Islam spread across the Middle East and into India in the east and all the way to Morocco and Spain in the west, this vast empire began to assimilate architectural styles from many traditions. Religious architecture was to become the most obvious symbol of Islam [Bartel,2003]. As mentioned in the introductory chapter, this research is focused on the Mamluk period which is characterized by the continuity and stability for more than 250 year of the governance of Egypt as shown on Fig. (2-1). The figure presents the evolution of Islamic architecture in Egypt and the position of the Mamluk era between the different historical periods. More precisely, the research studies Cairene complex religious buildings of the Mamluk period. Therefore, the chapter begins with a brief introduction of the history of the origins of the Mamluk dynasty and how it rose to power. It is assumed that this might be a great help in understanding the pride behind such monumental buildings which characterize this period.

The research attempts to discover the role of geometry in the architectural design of the complex religious buildings of the Mamluk period. Therefore, this chapter observes two parallel paths: The first path presents the types of buildings in Mamluk religious architecture and demonstrates the architectural vocabulary elements which the Mamluk architect depended on in the complex building design in order to explain the Mamluk religious architectural style. The second path explains the Mamluk architectural educational system in order to answer three main questions: The first question is how the architect was educated in the Mamluk period, which means understanding how the architect was prepared scientifically for his profession. The second question is how the science of geometry was imported to the architects. The third question is how the Mamluk architect could benefit from the science of geometry in his complex building design. This enables an understanding of the link between the architect's profession and geometry and discovers where the ingenuity of Mamluk architects lies in using geometry in the architecture design. Then the chapter goes to demonstrate the form and space in Mamluk religious architecture and explains how the urban context affects the religious building design, playing an important role in drawing the relationship between the architectural vocabulary elements of Mamluk religious architecture[1].

[1] This chapter forms the historical background. The next chapter analyses in more detail how the Mamluk architect used the geometry in the complex religious building design in general and in madrasa buildings in particular.

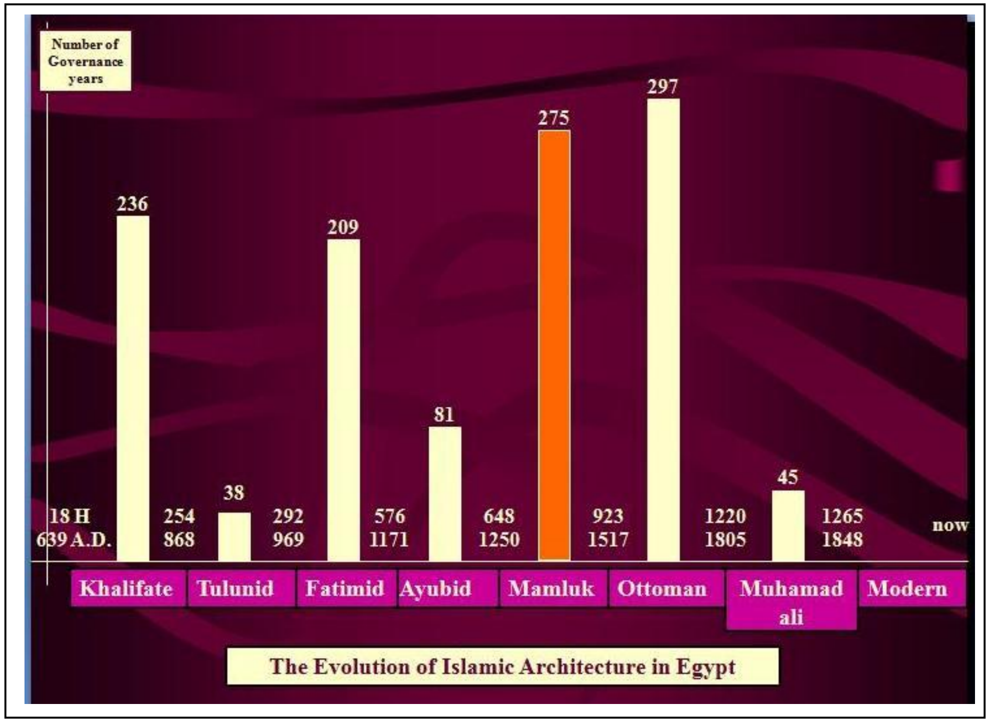

Figure 2-1: The evolution of Islamic architecture in Egypt (the researcher)

2.2. The Mamluk in History

Two points are discussed in regard to the long period Mamluks were governing Egypt. The first point is about how the Mamluks were able to establish their regime and how they rose to power. The second sheds light upon the scientific, religious and artistic life of the Mamluks in Egypt in order to explain the hidden aspects which affected their architectural production, demonstrating the atmosphere which introduced these wonderful buildings, and discover the main factors which formulated this prestigious architectural character.

2.2.1. The Mamluks on the Throne of Egypt

'Mamluk' comes from an Arabic word and means 'owned' or 'belonging to'. It is a name given to a slave who does not inherit slavery from his parents, but is taken as a ware refugee or is captured as a child and sold into slavery [Taqush,1997]p.15. The Egyptian Mamluks were young children, brought as slaves from non-Muslim areas into Egypt, educated, trained and set free by the Sultan.

The emergence of the Mamluk in political life in the Islamic world was during the Abbasid period. Al Mu'tasim was the first Caliph to depend on the Turkish Mamluks, when as Amir he bought around 3000 Mamluks in order to support his judgement against the Khurasanians. Al-Mu'tasim gave his Mamluks very important court positions and increased their influence and their privileges in Baghdad which led to a tremendous hatred towards them from the people.

During the followings periods, the Ikhshidi period and Fatimid period, nothing had changed to affect the strategy of keeping the Mamluks around, as a symbol of power to the ruler. Except that Fatimid Caliph (365-386 H./ 975-996 A.D.) made his Turkish Mamluk the leader of his army. From this point onwards the threat of the Mamluks' influence increased and later they became the governors of Al-Sham (Syria and Palestine).

The Ayyũbids were strengthening their army with the help of the Turkish Mamluks, positioning them within the palace court and teaching them to be the best generals and officers. During the Ayyũbid period the Mamluks began to play an effective role in the history of Egypt, because they were the ones who helped Salah al-Dĩn in his struggle to unify Egypt and Syria under his rule. Their numbers increased after the death of Salah al-Din in 589H./1193A.D [Taqush,1997]p.24. It was obvious that whoever gained the Mamluks' loyalty would seize the throne. Evidently, the Mamluks had become the dominating power in Egypt and Syria. At that time they had the power to dispose a Sultan and appoint another. However, no Mamluk would dare to aspire to the judgement of Egypt due to their Mamluk origin.

The rise of the Mamluk regime power in Egypt was the result of a chain of events set in motion by the death of the Ayyũbid Sultan al-Malik al-Salih in 1249 A.D. Al-Malik al-Salih created a corps of Turkish Mamluk soldiers, the largest in Egypt's history up to this date, and made this corps the mainstay of his army. These Mamluks were stationed in barracks on an island on the Nile near Cairo called al-Rawdah, and became known collectively as Bahris. The Bahris had already demonstrated their military expertise by inflicting a defeat on the Crusader army of Louis IX, who had invaded Egypt just before al-Malik al-Salih's death. After the end of the Ayyũbid rule in Egypt, the Mamluk agreed to choose Shajar al-Durr as a country Sultan. She married Prince Izz al-Din Aybak, who was the first of the Mamluk sultans of Egypt. Then the Mamluks took over Egypt and chose Cairo to be their capital.

The Mamluk adopted a system where the rule belonged to the most powerful; the one powerful enough to seize the throne and eliminate all rivals ['Ãshũr,1959]Pp.9-12. This means the survival of the fittest. It reflected on the circumstances that had given rise to the Mamluk take-over and the cancellation of Ayyubid legitimacy. Although the method of succession was a variable of Mamluk politics, certain basic features of the Mamluk system remained constant throughout the two and half centuries of Mamluk rule. The most striking of these features was the essentially foreign character of the military class. The Mamluk system seems to have been deliberately designed to keep the military aloof from the indigenous population [Al-Nabbahĩn,1981]p.127.

Regarding the Arabs and the Islamic world's negative opinion of the Mamluks and their policies in any country in which they had existed, the Arabs and the Muslims owed them two important strategic incidents events [Tantawy,2002]p.17: First, the Mamluks succeeded in stopping the Crusaders from completing their Christian mission of taking over the Muslim territories. Second, the triumph on the Mongol army stopped the aggressive flow of the Mongols into the Islamic countries, demonstrating that the Mamluks were the only Islamic power left in the Middle East. After the great victory of Mamluks against the Crusaders and the Mongols, most of the Islamic and Arab countries accepted the Mamluks as the rulers of Egypt and Syria, disregarding their slave origins.

Mamluk history is divided into two periods based on different dynastic lines: the Bahri Mamluks (1250–1382) of Qipchaq Turkish origin from southern Russia, named after the location of their barracks on the Nile (al-bahr, literally "the sea," a name given to this great river), and the Burji Mamluks (1382–1517) of Caucasian Circassian origin, who were raised in the Citadel (al-burj, literally "the tower") [Yalman,2000]. All the Mamluks who were brought to Egypt were slaves in the royal barracks. They were manumitted and given responsibilities in the Mamluk hierarchy after receiving instruction in Arabic, the fundamentals of Islam, and the art of warfare. The Mamluk history, in Egypt can be summarized in the following table.

Date	Actions
1250 A.D. (The beginning of Mamluk regime)	The Mamluks general use their strong position in the Egyptian state to replace the Ayyubid sultan with one of their own.
1250-1382 A.D. (The Bahri Mamluks)	Bahri Mamluks came on the throne of Egypt.
1382-1517 A.D. (The Burji Mamluks)	A Mamluk commander of the Burji camp usurps the sultan throne.
1517 A.D. (The end of Mamluk regime)	The Mamluks are defeated by the Ottoman Sultan I, and Egypt becomes part of Ottoman empire.

Table 2-1: Mamluk history in Egypt (the researcher)

2.2.2. Mamluk Scientific, Religious and Artistic Life

The political, social and the economic life in the Mamluk era are not discussed, but a brief description is given. The scientific, religious and artistic Mamluk life is discussed in detail; furthermore, explaining the important factors affecting it. It is assumed that this is the shortest way to explain the status or the level of the architecture of that era.

The social life in the Mamluk era was characterized with numerous celebrations, some religious and others national, according to which many various buildings such as khanqahs, mosques and schools were constructed to serve various activities: religious, social and educational.

In order to describe the economic life in the Mamluk era, it can be said that Cairo was not only a military power or just a country full of natural resources, but rather a main trade centre. For a long time it was the passage between the east and the west, Europe and Asia. The valuable goods that came from Persia and India had to be transhipped through Suez and taxed by the customs officials of the Sultan. Therefore, the Mamluk's economic power mainly depended on the commercial route between the east and the west. Egypt is strategically located in the middle of that road. In the era of the Mamluk state Egypt had a considerable economic status, as a result of the recovery and the prosperity of all aspects of life; industry, trade and agriculture. The consequence of the success was the large architectural prosperity in Egypt.

2.2.2.1. Scientific and Religious Life of the Mamluks

In the era of the Mamluk sultans, Egypt became the main centre of scientific activity, where scientists, scholars and students from various countries gathered [‘Ãshũr,1992]p.157. This is because the revival of the Abbasid Caliphate in the hands of the Mamluks in Egypt in 659 A.H. provided an opportunity for Cairo to inherit Baghdad and become a big and important centre of scientific and religious activity in the Islamic world. The best proof of this activity is the big heritage in various arts and sciences such as historical books and literary encyclopaedias, which the scientists of that era had left. The most significant evidence of that great scientific activity in the Mamluk period is the large number of schools which were established by the sultans from the reign of Sultan Baybars (1250 A.D.) onwards until the reign of Sultan Al-Ghuri (1517 A.D.). It must be mentioned that this scientific activity could not flourish in Egypt in the Mamluk era without the encouragement given to some of the Mamluk sultans to science and scientists [‘Ãshũr,1976]p.341. Schools were not the only religious institutions which gave the Mamluk era its special religious character. That era witnessed the establishment of many other institutions such as mosques, khanaqahs and others. It has to be noted that both the school and the mosque in that era had a dual role in the service of religion and science. The difference between the two is that the school firstly targeted the service of the science activity and secondly the religious activity came implicitly through the teaching of religious sciences. The first goal of the mosque was the revival and service of the religion, and then came the use of some of the mosques for teaching.

As for the religious life, it is recognized that in the era of Mamluk Egypt witnessed unprecedented religious activity. The secret in this great religious activity is the great feeling of Mamluks themselves as strangers in the country and among its people; they also feel that they were the usurpers of the throne of governance from the legal owners. Therefore, they used religion and its devotees as a means to bring them closer and win over the hearts and minds of the common people over which they ruled [‘Ãshũr,1976]p.349. As long as the Mamluks were Muslims believing in Allah and His Messenger and were keen on the establishment of religious rituals and constructing mosques in the sake of Allah, they were good referees and it was not necessary to think about their origin and the method of arrival on the throne and in the government.

2.2.2.2. Artistic Life of the Mamluks

The progress of the arts at any time and place is strongly associated with the state of economic life and the availability of money. Perhaps the biggest feature the Mamluk state was characterized with was the wealth, richness and the availability of money. The most characteristic feature of the Mamluk period was the huge building activity that took place, particularly in the domain of religious buildings. Egypt prior to the Mamluks had not known such a flourish of the arts, literature, public works, as well as an array of other culture activities. The biggest surprise of the Mamluk era is that the military elite, selected as it was without having roots in Egypt, was a patron of such magnificent mosques, madrasas and khanqahs.

Arts in the Mamluk period were divided into two groups. The first group includes architecture, painting and sculpture which is called the major art. The second group includes small crafts called the minor-art which require high accuracy, superior genius and great skill [‘Ãshũr,1976]p.383. In the Mamluk period the artistic life reached its highest level of sophistication. Therefore, this section analyses in detail the architecture as one of the most important elements of the artistic life in the Mamluk period.

The existing architecture of the Mamluk period in Egypt is one of the most important visual sources indicating, together with its decoration, related emblems and inscriptions, the prosperity of this period, and the achieved progress and development in different life aspects. The two periods of Mamluk age (1250 – 1517 A.D.) were known as the golden age in the history of Islamic architecture in Egypt [‘Ãshũr,1976]p.385. In the Mamluk period there was a great turnout on the construction of buildings: schools, mosques, and tombs. This is demonstrated by the diversity, sophistication and elegance in the various architectural elements: the facades, minarets, domes and the decoration of plaster and marble. The buildings of the Mamluk period can be divided into religious and civil. The religious buildings such as mosques, tombs, domes and schools, together with the civilian buildings such as palaces and baths, and all monuments (despite the fact that some of them no longer exist) show a supremely artistic taste and magnificence of construction.

Mamluk architecture could be seen from three points of view. The first point is its visual features; the second is its vocabulary or elements; and the third is the Mamluk architecture style. These different points of view would help in understanding how the Mamluk architect was able to arrange his architecture vocabulary and elements under the control of his architecture visual features to reach that fantastic architectural style in his final architectural production.

The main architectural visual features of Mamluk architecture are presented here briefly, including commonly used materials, forms and planning arrangements, building types, decorative motifs and techniques.

1- The architecture of the Mamluks is primarily built of natural stone. Wood is used for elements such as doors, panels and mihrabs, and in the lattice window screens. Domes are commonly built of stone. Stucco is used for decorative elements.
2- The four-iwan plan, which was introduced earlier in the architecture of Egypt by the Ayyubids, emerged as the most common plan for the religious buildings of the Mamluks, including mosques and madrasas, as well as the numerous structures that combined both. These madrasas and mosques often include a domed mausoleum for the building's patron [Al-Asad,2006].
3- The minaret as an important visual element has often different sections along the component parts of its shaft, resulting in an arrangement referred to as the three-tiered minaret. This minaret has a square base, followed by an octagonal shaft, which in turn is proceeded by a circular shaft, the upper part of which might be colonnaded. Balconies resting on Muqarnas vaults may separate these sections from each other. Other minaret sections such as fully octagonal ones are also common.
4- The shapes of the domes which are always attached to the mausoleum in Mamluk architecture often have a cylindrical drum and a pointed profile. Initially, squinches and later, pendentives in many cases consist of Muqarnas units used as the transitional zone for the dome. In earlier examples wood is used for these transitional elements, but later stone prevails.

Both round and pointed arches are used. However, pointed ones are more prevalent, especially in later Mamluk architecture.

5- In Mamluk architecture the buildings are generally not symmetrical; instead they tend to emphasize the use of balance over symmetry in their overall composition. The alignment of the building with the different directions of the street and the Qibla is emphasized, and this results in a rich variety of entry sequences to buildings that mark dramatic changes in axis. The buildings are monumental in scale.
6- The Mamluks used calligraphy extensively. Also, the Ablaq technique, which was introduced during the late Ayyubid period, became widespread and even characteristic of Mamluk architecture. The use of stone Muqarnas is ubiquitous. The most elaborate examples articulate the half-domes located over entry portals [Al-Asad,2006].
7- The architecture of the Mamluks is very cosmopolitan in nature. Cairo was an important international political and commercial centre, and it attracted artisans from various regions. Mamluk architecture consequently incorporates influences from al-Andalus, North Africa, Crusader, Central Asia, India and Persia [Al-Asad,2006].

2.3. Mamluk Religious Architecture

Mamluk religious architecture has many aspects that can be discussed. The focus is on three main aspects. First the types of buildings which the Mamluks constructed in order to serve religious activity are demonstrated. Because of the big variety in the types of buildings in the Mamluk architecture all religious buildings cannot be presented in detail. Two types are introduced: the madrasa and the mosque, because firstly the Mamluk religious complex buildings (the research case study) always include them. Secondly the buildings compositional vocabularies are explained, in order to discover the geometric relationship between all these vocabularies in the building composition. Thirdly, the Mamluk religious architectural style is explained, which comes from mixing the composition vocabulary under the control of the era culture and by the use of geometry science.

2.3.1. Types of Buildings in Mamluk Religious Architecture

The most striking feature of Mamluk architecture in Egypt, whether in religious, commercial, or residential construction, is its complex morphological language behind the numerous constructed buildings. The types of buildings in Mamluk architecture can be divided into three main categories. The first type is royal constructions such as palaces, hotels (khans[2]) or Wikalat[3]. The second type is the public constructions such as the market (suqs), bath houses (hammams), caravanserais[4] as well as private

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[2] **Khans** (singular: Khan) Buildings which combine the functions of hostels and trading centres. Standard features which one might expect to find in a khan are stables, store rooms, sleeping accommodation and a mosque (see Andrew Peterson, ***Dictionary of Islamic architecture***, p.148).

[3] **Wikalat** (singular: Wikalah) Urban buildings combining the functions of khan, warehouse and market (see Andrew Peterson, ***Dictionary of Islamic architecture***, p.302).

[4] **Caravanserais** are the roadside buildings which provide accommodation and shelter for travelers (see Andrew Peterson, **Dictionary of Islamic architecture**, p.51).

shops. The third category is the complexes, which gather inside one building many functions - religious, educational, residential, commercial, cultural, social and funerary functions - such as tomb-madrasas or tomb-khanqahs and mosque-madrasa. Because of these big diversities in buildings types in Mamluk architecture, besides the fact that main focus of the research is on the Mamluk complex religious buildings, the main two religious building types (madrasa and mosque) are discussed in detail. The school (madrasa) and the mosque are discussed because they were mainly constructed in order to introduce religious alongside educational activities. Through its educational activities they play a big and important role in the preparation process of the Mamluk architects.

2.3.1.1. The Madrasa

A madrasa is a building which functions as a teaching institution primarily of Islamic sciences [Petersen,1999]p.168. In the Mamluk era the madrasas became a common feature in most cities and were used to train administrators. they was characterized by the four-iwan plan, where each iwan represented one of the four Islamic jurisprudence schools, and they were later developed to become the dominant architectural form with mosques adopting their four-iwan plan[5].

A simple examination of a range of surviving religious Mamluk buildings reveals a discernible preference for geometrically ordered spaces with isotropic spatial qualities. There was a tendency to organize spaces symmetrically around a central point. For example, the formal composition of a dome on a geometrically regular base or a courtyard with a central fountain and four vaulted iwans, and other symmetrical elements are recurrent in the madrassa building type. There are rich tectonic and regional variations of course, but the same spatial order is traceable in buildings that serve secular as well as religious purposes, furthermore the underlying spatial order remains consistently visible from the beginning of the period to the late Mamluk era [Akkach,2005]p.151.

Probably the most famous building of Mamluk Cairo is the Madrasa of Sultan Hassan. This was built on a four-iwan plan madrasa and was the first madrasa in Cairo to be accorded to the status of a congregational mosque. The building consists of a square central courtyard with four great iwans. The largest of the iwans is a prayer hall behind which is the domed mausoleum. Between the four iwans are four separate courtyards one for each of the orthodox Sunni rites of Islamic law [Petersen,1999]p.48.

2.3.1.2. The Mosque

Mosque - masjid, and jami - are the Islamic sacred places of worship and are the most important Islamic building. The word "mosque" comes from Arabic and stands for "a place of prostration" or bowing down to Allah. Besides being a place of prayer, the mosque was also used as a "community centre" for a combination of reasons: a school, for political and social meetings, a place for judging cases, and other functions in the Islamic community [Abd-Elfattah,2008], which the Muslims have constructed

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[5] At the beginning, learning in the Mosque/Madrasa was limited to one: that of the *emir* or sultan who built it. Later it comprised tow schools of jurisprudence and became the *Madrasa thuna'iyyya* or “double Madrasa”. This was followed by the triple and quadruple *Madrasa* for all four schools of jurisprudence.

in a rich variety of forms and styles. Austere or elaborate, simple or monumental, the mosque serves a uniquely Islamic function and has, therefore, been widely recognized as the expression par excellence of Islamic architecture [Akkach,2005]p.193.

According to their size, mosques can be divided into: Masjid and congregational mosque (Jami). The last is the most important public construction in the city, because besides its religious role it plays the role of a community centre for all activities, commercial, social, cultural and political activity [Hassan,2002]p.15, so that it is always located and constructed in the country side. Despite the large body of literature on the origin and development of mosque architecture, the curious relationship between the act of prayer and the architecture of the mosque, between the building composition geometry and the building space form, has rarely been profoundly explored.[6]

2.3.2. The Vocabulary Elements of Mamluk Religious Architecture

The Mamluk religious monuments were essentially a flexible composition of modules combined ad hoc, according to the requirements of each site. Ideas were pragmatically subordinated to the particular circumstances of a building's location and its patronage. Because each monument was designed to take account of a variable street perspective and other urban requirements, its layout was singular [Behrens-Abouseif,2007]p.71. In this section an attempt is made to present the geometric aspects of the main architectural elements used in the composition of the religious buildings in Mamluk Cairene. These elements are: the entrance, the courtyard, the praying hall, the iwan, the dome and the minaret. In order to uncover the geometric principles of the building design, an analysis of the geometric composition of these architectural elements will be conducted. This will show that the geometric analysis provides a better understanding of Mamluk religious architecture because this analysis depends on an implicit geometric knowledge that was ignored in almost all previous historical analysis. It has to be taken into consideration that this is not a historical presentation of these monuments, but only explains how Mamluk architects depended on geometric relationships and used geometric shapes in their formal components in pure expression or hidden order.

2.3.2.1. The Entrance

From the analysis of the entrance in the Mamluk religious buildings it is found that it consists of four main parts: the entrance stair space, the portal space, the portal, the entrance hall. The entrance facades always followed both the alignment of the street, and the orientation of the prayer area (towards Makkah), which gave rise to the bent corridor (Majaz) as a mediating between the street and the courtyard (sahn), so in almost all Mamluk religious buildings the entrance four parts are always followed by the offset corridor, and all of them were formed to take the bent entrance form, as shown in Fig. 2-2(a-c). In madrasas and khanqahs, which included living quarters, the bent entrance had the advantage of protecting the privacy of the resident community

[6] Mosque architecture and its form, historical development, sociocultural contexts, and symbolism have been discussed in numerous studies. See, for example, Martin Frishman and Hasan-Uddin Khan (eds). ***The Mosque: History, Architectural Development and Regional Diversity***, 1994; Robert Hillenbrand, ***Islamic Architecture: Form, Function and Meaning***, 1994, chapter 2.

[Behrens-Abouseif,2007]p.86. The bent corridor provides utilitarian functions, for example in this area the ablutionaries and the services quarter are located, because these elements do not need to be regular in form as the entrance does and the prayer hall.

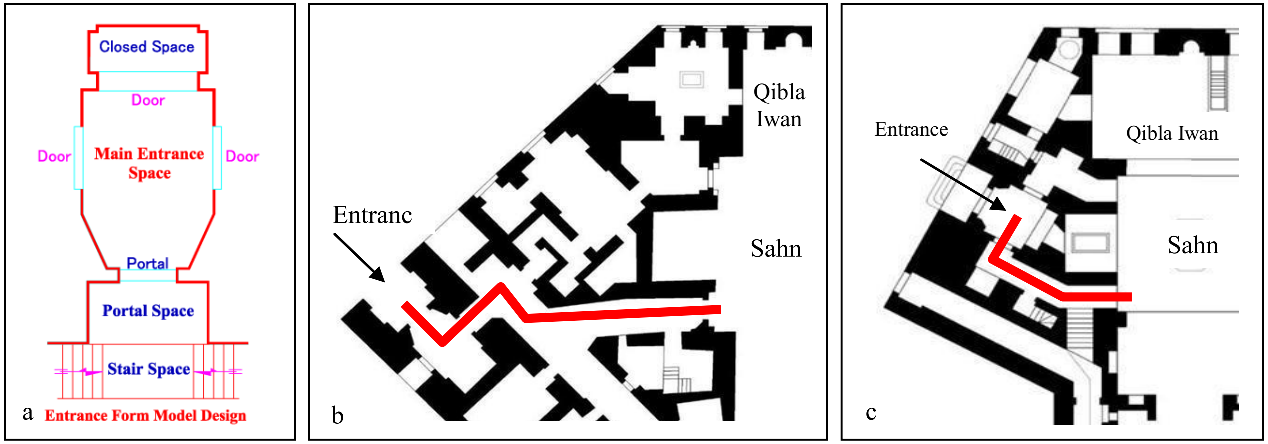


Figure 2-2: a- Entrance form design in Mamluk religious buildings
b- Bent corridor in Madrasa of Umm al-Sultan Sha'ban
c- Entrance form and Majaz in Complex of Amir Azbak al-Yusufi

The entrances of the Mamluk religious buildings were constructed recessed into the facade rather than protruding into the relatively profane street. The composition of the portal space goes to the full height of the facade, with the silhouette of the recessed area leading up to a semi-dome or a vault with the curvature of a pointed arch covering this recess [Gabr,1992]p.342. The entrance hall has a simple geometric composition; it is accentuated vertically by having either a dome on squinches and stalactites, or an elaborate groined vault for its roof.

Mamluk portals were usually flush with the rest of the elevation with a recessed doorway with some exception, such as the Madrasa of al-Sultan Hassan and the Madrasa of Barquq. In these two buildings, the portals are probably projected to avoid having the corner of the angled portal interfere with the rest of the facade. The portals also have the same height as the rest of the elevation to maintain the sky-line of the building. However, the inscription band that exists in some of the elevations usually stops or frames the entrance decoration [Tantawy,2002]p.64.

Figure 2-3 shows three parts from the entrance main parts (the stair space, portal space and the portal) and the geometric shape compositions which cover the portal space in different examples from the Mamluk religious buildings.

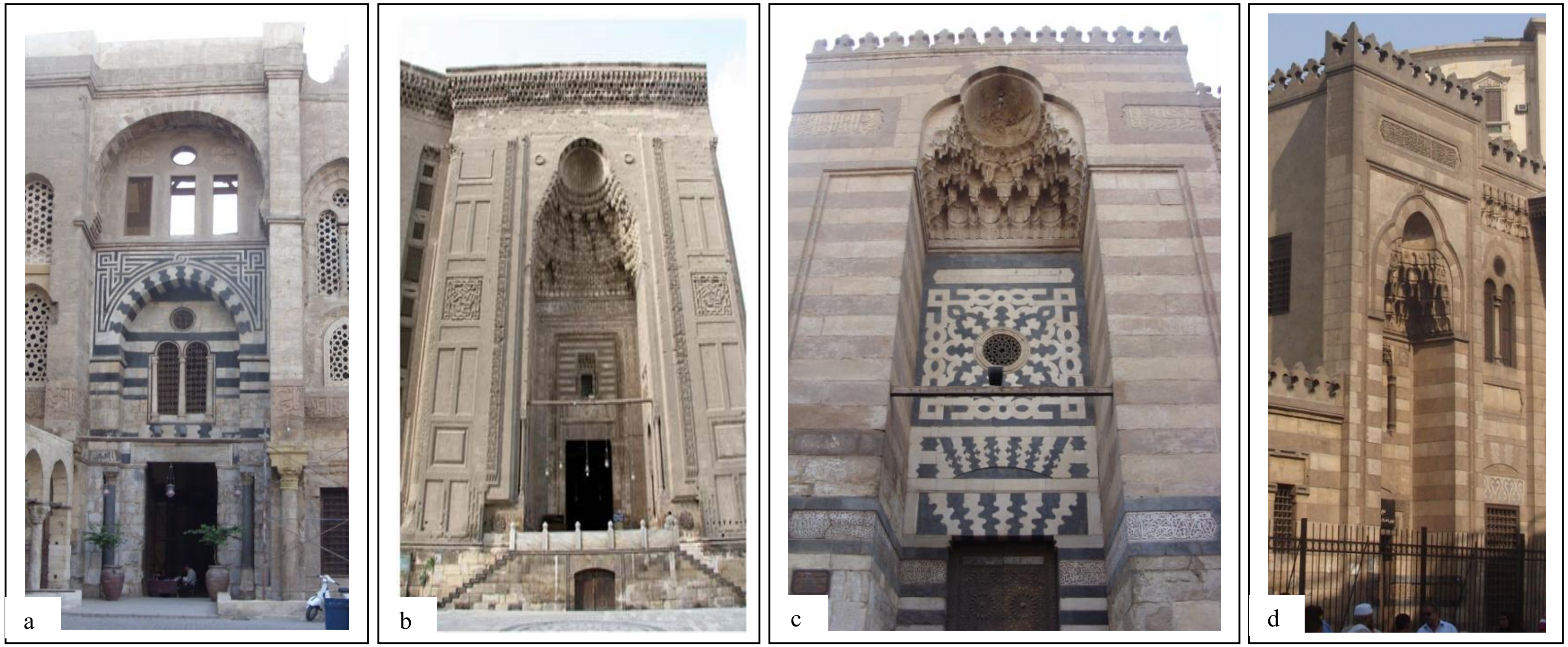


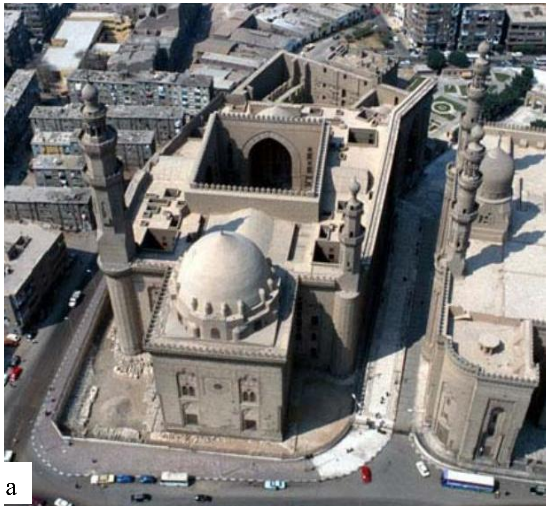
Figure 2-3: The geometrical compositions of entrances in Mamluk religious buildings.
a- Madrasa of Sultan Qalawun, b- Madrasa of Sultan Hassan, c- Madrasa of Sultan Barquq, d- Mosque of Qadi Zien al-Din Yahia.

2.3.2.2. The Courtyard (Sahn)

The courtyard as widely explained in art history is nothing more than a utilitarian architectural device provide privacy and to ameliorate the harshness of the climate. The courtyard can form part of buildings such as mosques, schools, and houses; or on a larger scale it can become a large garden or the central space of an entire city. In the many cases, where the internal courtyard is a predominant spatial element, regular geometric and spatial qualities are evident. Whether a centralized courtyard is the determining model of an entire architectural complex or only a part of it, it normally expresses, in one form or another, the underlying order of a concentric composition [Akkach,2005]p.155. The concentric composition represents architectural designs that are laid out about a stationary centre, expressing the spatial order of the three-dimensional cross in a static manner. Two models are typical by ordering spaces: a centralized enclosed space and a centralized open courtyard. The second model is seen in the Mamluk period when the courtyard centered on fountains and surrounded by iwans, and this became a prototype for both secular and religious buildings in the Mamluk era.

Although the first four-rite madrasa was found at Baghdad, the first madrasa of four perpendicular arranged iwans plan was found in Cairo; this plan was Egyptian in origin and it is practically unknown outside Egypt [Creswell,1922]p.43. By the choice of the courtyard as the heart of almost Mamluk religious building, the Mamluk designers obtained a more feasible "urban" form, capable of providing that the centre in religious building design acts as a generator of form, and the whole organization of the building form starts from the centre extending the design outwards[7]. This architectural tool dominated the architectural activity of "place making" and during the Mamluk period in Egypt became the prototype of place, unifying the individual parts of a building with the whole outside.

The classical hypostyle or Riwaq[8] plan, consisting of arcades surrounding a courtyard, had not been in use between the reign of al-Zahir Baybars and the third reign of al-Nasir Muhammad [Behrens-Abouseif,2007]p.73. During the Mamluk periods the two-iwan plan continued until the Madrasa of al-Nasir Muhammad in al-Mu'izz Street which was the first four-iwan madrasa plan [Tantawy,2002]p.99. The geometric prototype of Mamluk religious buildings can be described as a hollowed cube, turning blind windowless walls to the outside, with all the spaces of the building looking inward into a courtyard. The spiritual atmosphere of the religious building is achieved by isolating the prayer or the students from the exterior environment. Hence, achieving a comforting temperature inside the building helps at the same time to create an atmosphere serving a spiritual purpose.


a


b

Figure 2-4: The spatial order of the centralized open courtyard model
a- Madrasa of Sultan Hassan, b- Khanqah of Sultan Faraj Ibn Barquq

[7] Chapter 4 shows how the Mamluk architect could start his complex religious buildings design from the centre extending the design outwards.
[8] **Riwaq** is arcade or portico open on at least one side.

2.3.2.3. The Iwan

The iwan is a vaulted hall, walled on three sides, with one end entirely open. Iwans were common in the Sassanian world before Islam and rapidly became incorporated into Islamic architecture. The greatest period of diffusion was under the Ayyubids in the 10th century when iwans became established as one of the basic units of Islamic architecture [Petersen,1999] p.130. One of the most typical iwan arrangements is to have four iwans opening on to a central courtyard. This later became a typical arrangement for mosques, madrasas and palaces in the Mamluk era.

Geometrically the iwan can be described as a three dimensional space resulting from the growth of the arch (be it pointed or semi-circular) along a horizontal axis. The iwan form was used ever since in madrasa and khanqah as a space for prayer and teaching.

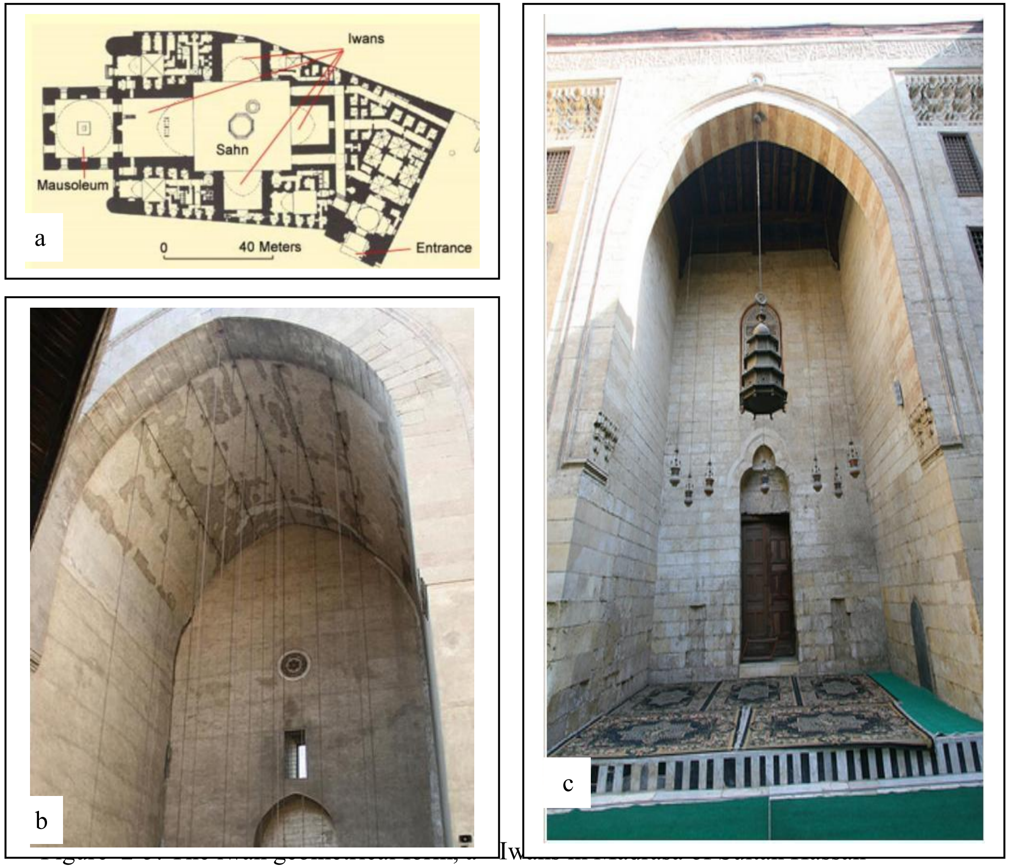


Figure 2-8: The iwan geometrical form, a- Iwans in Madrasa of Sultan Hassan
b- Side iwan in Madrasa of Sultan Hassan, c- Side iwan in Madrasa of Sultan Barsbay

2.3.2.4. The Prayer Hall (Qibla Iwan or Iwan al-Salah).

There are three generic types appearing to accommodate the prayer hall, mainly in the forms of pillared rectangular areas in hypostyle religious buildings. The second form is vaulted iwans discarding the pillars. The third is a square-domed space such as Persian and Turkish examples [Gabr,1992]p.358. The Mamluks gradually abandoned the vaulted iwans they had inherited from their Ayyubid predecessors, which prevailed in the early Bahris period and were gradually replaced with a flat wooden-ceiling iwan opening on the courtyard with and arc [Behrens-Abouseif,2007]p.74. The Mamluk architects depended on pure geometric shapes in the form of the qibla iwan as the square and rectangle in the plan and cub in the volumetric composition.

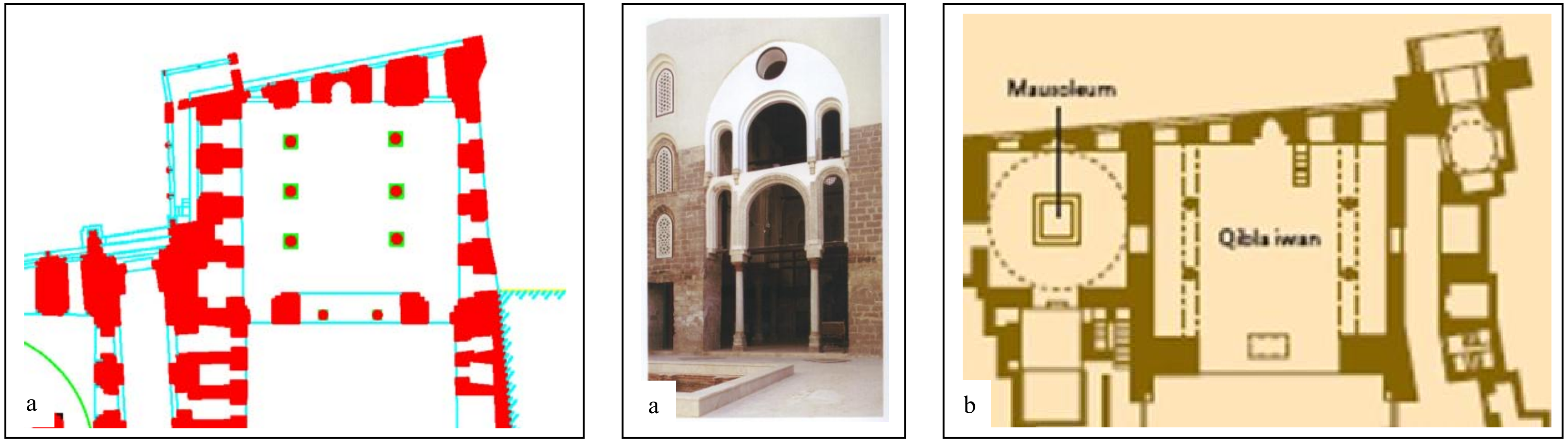


Figure 2-6: First type of generic forms of qibla iwan in Mamluk religious buildings: Pillared rectangular areas
a- Madrasa of Sultan Qalawun, b- Madrasa of Sultan Barquq

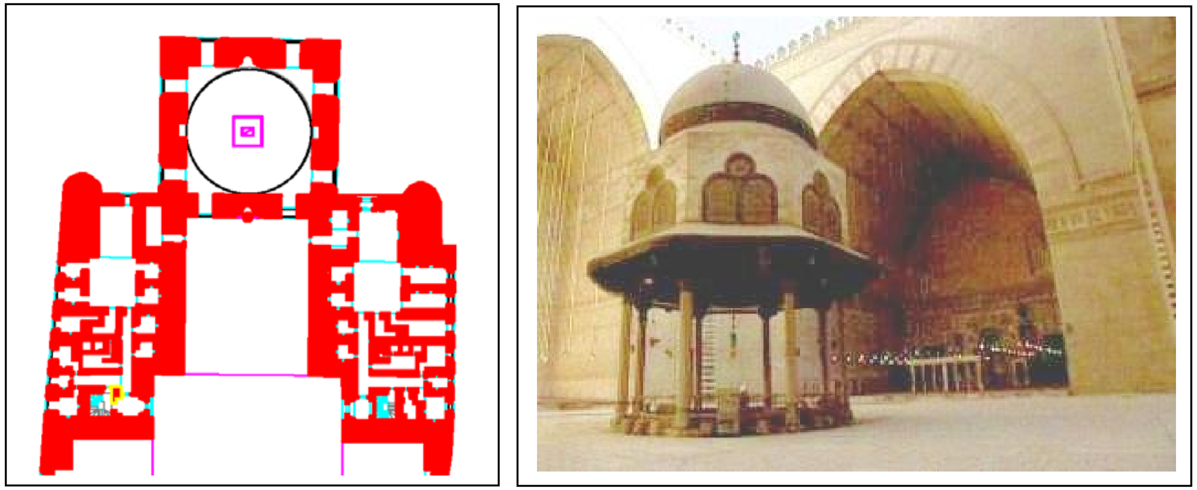
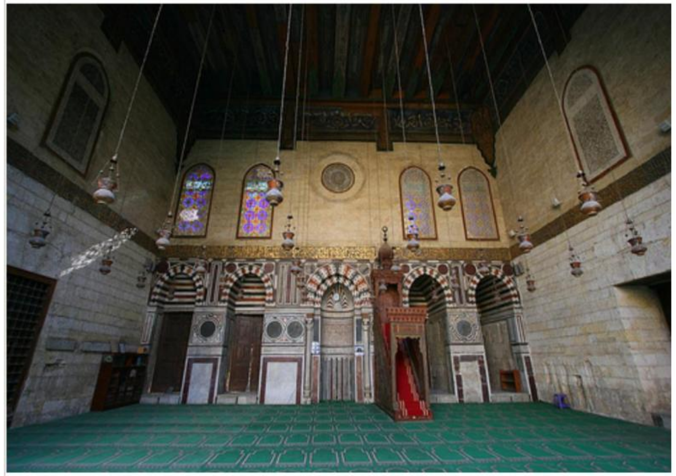


Figure 2-7: Second type of generic forms of qibla iwan in Mamluk religious buildings: Vaulted iwans as shown in Madrasa of Sultan Hassan

Figure 2-8: Qibla iwan vaulted geometric form in Madrasa of Sultan Hassan



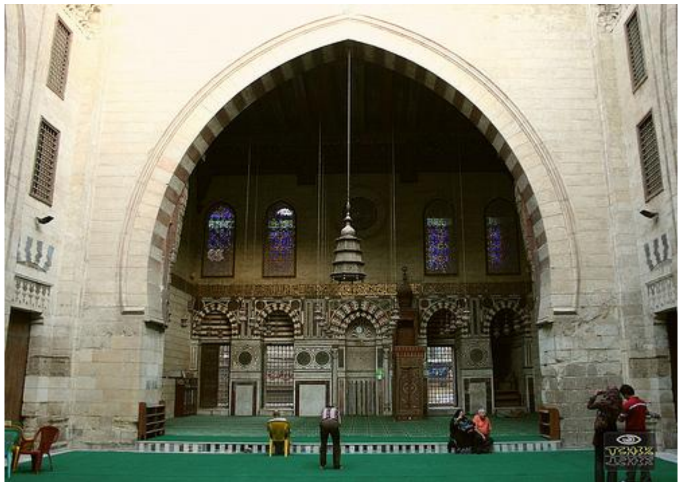


Figure 2-9: Third type of generic forms of qibla iwan in Mamluk religious buildings: Square space with horizontal wooden roof as shown in Madrasa of Sultan al-Ashraf Barsbay.

2.3.2.5. The Minaret

The Cairene minarets were the only ones in Islamic architecture to combine varying sections – rectangular, octagonal and circular – in one shaft. The origin of this feature goes back to the Fatimid period. In the second quarter of the 14th century there arose the use of masonry of unprecedented quality, which eventually inspired the dome builder. Most minarets of the late 14th century were entirely octagonal, but in the 15th century they combined an octagonal first with a circular second storey. The Mamluk designer replaced the rectangular-octagonal-cylindrical shaft, surmounted by a ribbed helmet, with a slender octagonal or octagonal-circular tower surmounted by an octagonal pavilion crowned with a bulb on muqarnas. By eliminating the rectangular shaft the minaret became a particularly graceful sculpture that gave Cairo's skyline its characteristic Mamluk cachet. The reign of al-Ghuri introduced for the first time the totally rectangular Minaret, with double and quadruple bulbs at the summit. The architecture evolution of the dome and Minaret did not take place at the same pace, however. Masonry supplanted brick earlier in minaret than in dome architecture [Behrens-Abouseif,2007]p.77-80. This easy transformation from one geometric form to another in the same composition reflects the importance role geometry on Mamluk three-dimensional composition.

In general, the minaret geometric form rose in four stages, square, octagonal, round, and on top a lantern or small cupola [Creswell,1926]p252. The Mamluk architect used a harmonic geometric system in the geometric transformation between the minaret different sections, depending on the use of the hidden qualities of geometry in his design. In the building geometric composition the minaret was preferably placed on one side of the portal or the other, supported by a solid buttress. It rarely stood directly above the geometric axis of the entrance. The elegance of the Mamluk minaret is due to the beautiful geometric proportion of the segments of the final height of the minaret, which shows that their geometric design skills played an important role in the development of the style throughout the Mamluk era. The following figures indicate a panorama of the Mamluk minarets in Cairo of the Mamluks.

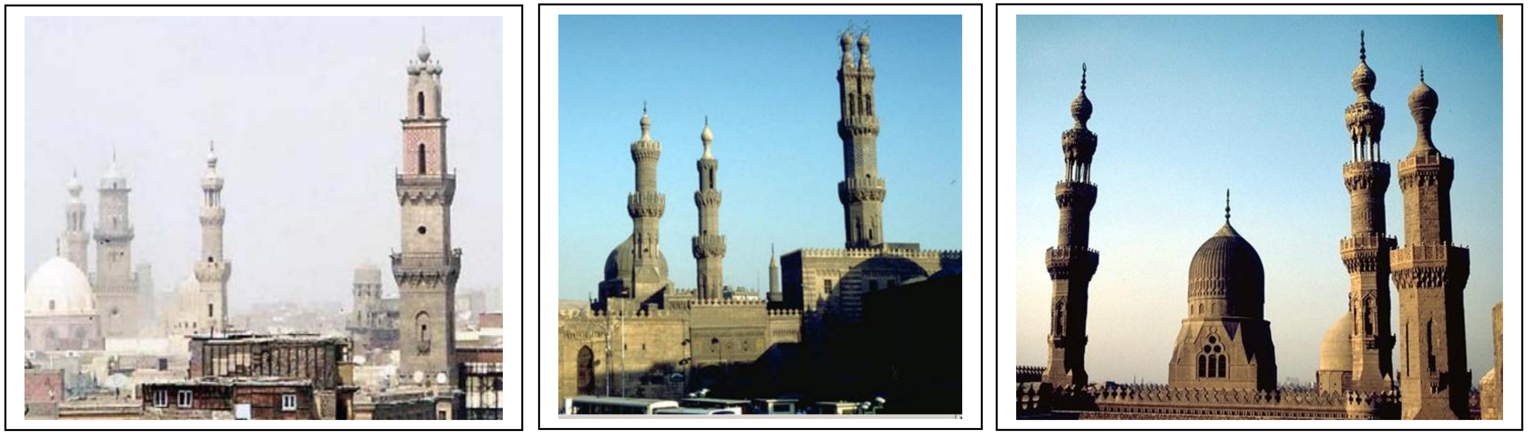


Figure 2-10: The panorama of the minarets in Mamluk Cairo.

2.3.2.6. The Dome

It is a circular vaulted construction used as a means of roofing. It was first used in much of the Middle East and North Africa then it spread to other parts of the Islamic world. Because of its distinctive form the dome has become one of the symbols of Islamic architecture [Petersen,1999]p.68. Until the mid-14th century; Bahri Mamluk domes displayed two types of profile: one that curves immediately above the drum, and one that curves above a cylindrical section at nearly one third of the dome's height [Behrens-Abouseif,2007]p.80.

One of the main problems of dome construction was the transition from a square space or area into a circular domed area. In general, there was an intermediary octagonal area from which it is easier to convert to a circular area, although there is still the problem of converting from square to octagon from the interior and the exterior zones. The transitional system is the structural and formal link between the wall and the dome and it is constituted by Muqarnas[9]. It is an aggregation of elements (pieces) according to a geometric grid that approximate, through regular polygons, the square (wall) to the circle (dome) [Pinto,2005]. For the inner transitional zone[10], Mamluk architecture made use of squinches as well as pendentives. The squinch is a mini-arch which is used to bridge a diagonal corner area whilst a pendentive is an inverted cone with its point set low down into the corner and its base at the top providing a platform for the dome [Petersen,1999]p.68. The squinches were inherited from the Fatimids and Ayyubids, who had developed the multiple-tier formula. The multi-tiered squinch has a Muqarnas configuration, each tier of niches corresponding to a bracket in the wall, while on the exterior the tiers appear as steps [Behrens-Abouseif,2007]p.81. On the three-dimensional composition the Mamluk architect by depending on geometric basis and the geometric relationship between shapes could transfer one shape to another. Figure (2-11) demonstrates different shapes the Mamluk architect used on the exterior transitional zones on the dome form.

In search for a decorative scheme for the transitional zone of domes, the builders looked at the architecture of stone minarets. The transitional zone of domes, in the forms of steps at the corners, was replaced in the 15th century by undulating or prismatic triangles to smoothen the transition from the cubic to the spherical space. These forms were borrowed from minaret architecture, which had already developed devices to decorate the base of minarets and their transitional zones, which fulfilled a similar function between the rectangular base and the octagonal or circular shaft [Behrens-Abouseif,2007]p.83. This manipulation with geometric shapes in spaces composition process in the two and three dimensions expresses and indicates the high degree of awareness that Mamluk architect gave it to the role of geometry in space design and shows how the reflection of geometry in architecture design can be achieved.

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[9] **Muqarnas** is a type of corbel used as a decorative device in traditional Islamic and Persian architecture. The term is similar to mocárabe, but mocárabe only refers to designs with formations resembling stalactites, by the use of elements known as alveole. Muqarnas takes the form of small pointed niches, stacked in tiers projecting beyond those below and can be constructed in brick, stone, stucco or wood.
The muqarnas are constituted by elements that are composed in overlapped rows producing complex compositions similar to "stalactites" in stone.

[10] For more details see, Laila Ali Ibrahim "***The Transitional Zones of Domes in Cairene Architecture***", Kunst des Orients, 1975.

Figure 2-11: Different geometrical shapes of exterior transitional zones in Mamluk religious buildings
a- The dome of Aytimish al-Bajasi, b- Mausoleum of Amir Yunus al-Dawadar,
c- The dome in Complex of Sultan Bersbay in northern cemetery, d- The dome of the mausoleum in Madrasa of Sultan Qaytbay.

The geometry have had a fundamental role in projecting and the building of the architectural form in Islamic eras through the treatises of practical geometry [Pinto,2005]. The dome is one of the Mamluk religious features whose form depends mainly on geometry. The space under it may be almost square and the dome may take a circular shape, and with the help of geometry the Mamluk architect could transfer one shape to another on the volume composition. A study of Mamluk geometry, in particular the geometric profiles of the domes, permits us to advance two fundamental questions on the geometry of design process used in the Mamluk architectural work: What kind of knowledge (applied geometry) was necessary for Mamluk builders? What were the geometric schemes used in Mamluk architectural works? Searching for the hidden geometric code of Mamluk religious architecture tends to give an answer to these kinds of questions and solves the mystery of the design process, imagining or visualizing of the geometric schemes which the Mamluk architect had used it in his architectural works, and understanding how the domes geometrically had been done.

The domed surface richly decorated by geometric patterns. The patterns carved on stone domes evolved from ribs to zigzag and other geometric and floral all-over design, and culminated in geometric star composition. The study of the three-dimensional character of the geometric motive applied to the surface raises interesting questions related to the techniques of optic and geometric deformation used for proposing the pattern on the surface of the dome. Figure (2-12) shows different geometric decorations on the Mamluk domes.

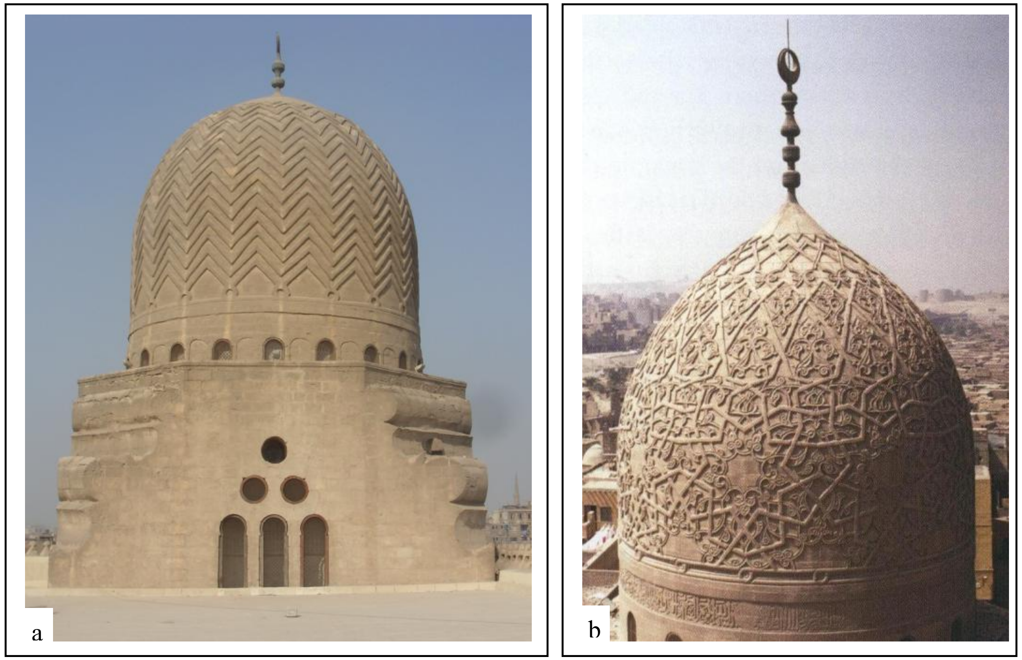

Figure 2-12: The dome geometric decoration
a- Mosque of Sultan Muiyyd Shaykh,
b- Complex of Sultan Qaytbay.

2.3.3. The Mamluk Religious Architectural Style

The architecture of Egypt during the Mamluks was a direct reflection of three gathered cultures in a homogenous forms and style [Tantawy,2002]p.34.:

- The Egyptian Muslim Arab culture: represented in language, Islamic law, believes, and way of life.
- The Egyptian Coptic Christian culture: represented in the native art and skills.
- The Mamluk culture: which was a continuity of the Ayyubid perception and principles.

These three cultural poles dominated Egypt for the two centuries of Mamluk rule. As a result of that atmosphere many developments took place in the Mamluk religious architecture during the Mamluk era.

In the Mamluk era, architectural style is divided into two periods: the Bahri period and Burji period. However, there is no certain date when the Bahri style changed to Burji style; similarly, there is no certain date of the formation of the Mamluk style in general [Tantawy,2002]p.60. This is because the Mamluk architects were very flexible in their design methods always trying new ideas but also returning to the old, depending on the context of the building. That led to unity of form and diversity in treatment between the two period’s styles. This diversity is a response of the development in design skills and the extension of urban fabric in Cairo. Here the main features of Mamluk architecture that form the Mamluk architectural style are presented. It has to be taken into consideration that presenting and demonstrating the geometric aspects in these features would explain the inherent geometric rules and geometric principles of design in these architectural masterpieces and help to understand where the creativity at Mamluk architectural style comes from.

2.3.3.1. The Open-Ended Composite Plan

The open-ended plan means that at the end of the plan composition the plan does not stop, but its formation is extended to provide a new totally different function about the function of the plan composition. This type of the open-ended composite plan is a development of the iwan court, which has been observed in al-Salih's Madrasa, and it was to become a major feature of Mamluk architecture [Yeomans,2006] p.137. For example, Madrasa of Qalawun and Madrasa of Sultan Barquq provide open-ended extensions at opposite ends of the sahn, as shown on Fig. (2-9), but at the same time the geometric relationship which combines and gathers all the plan components continues to also cover the new function added at the end of the plan composition.

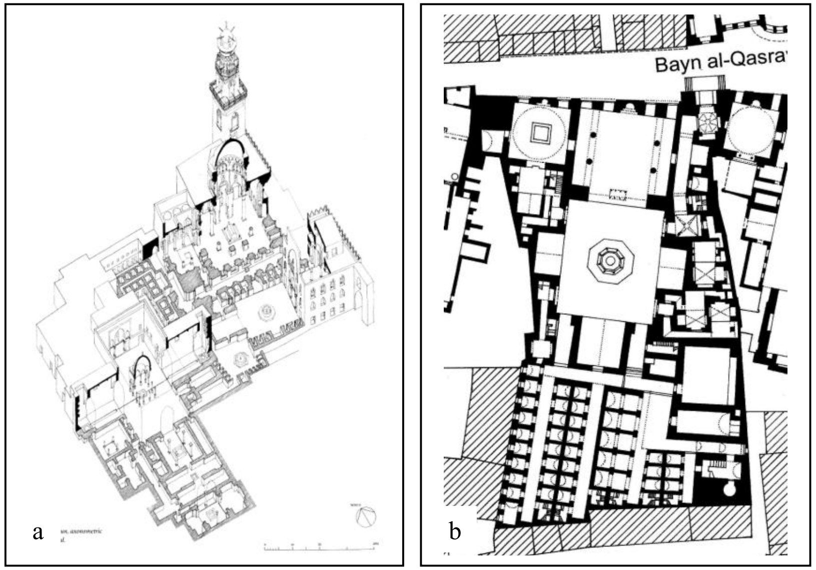

Figure 2-13: The open ended composite form
a- Madrasa of Sultan Qalawun, b- Madrasa of Sultan Barquq.

2.3.3.2. The Sophisticated Fenestration System

In the Mamluk era, although the facade was clear and organized, the building behind it was not, even though the space and land were available to accommodate any arrangement. For example, in the Madrasa of Sultan Hassan (1356 A.D.), the area of the building was suitable to put clearly arranged and regular spaces in the building design, but the designer used a very high degree of complexity in the arrangement of the inside spaces and a very high degree of simplicity in the fenestration system in the design of all building's facades.

From the geometric analysis of the religious buildings plans and elevations, it had been found that the fenestration system is dependent mainly on a repetitive and ordered geometric system in selecting the position of the windows in plan and elevation. It could be seen that the geometric position of the windows on the Mamluk fenestration design system on the right and left of the entrance is totally typical in plan, although the interior function of the behind spaces is different, as shown in the fenestration geometric design system in the Madrasa of Sultan Qalawun in Fig. (2-10)

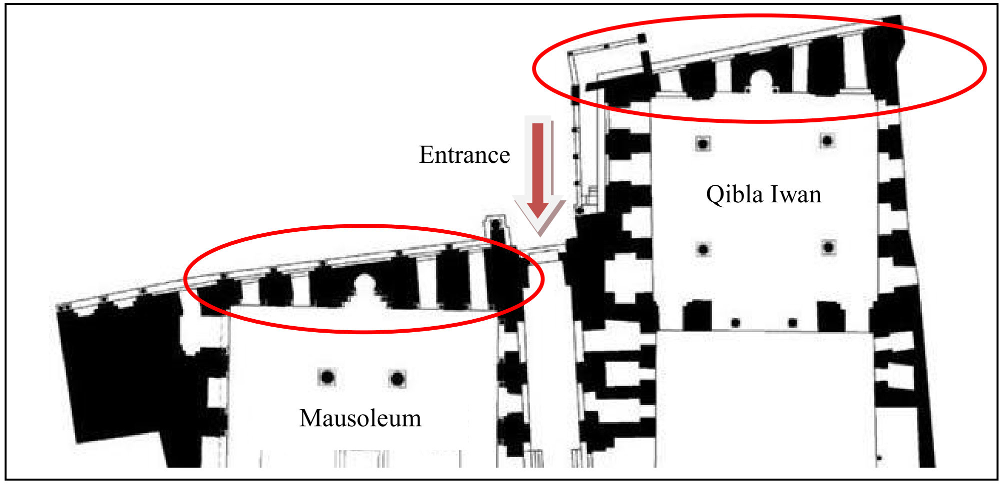

Figure 2-14: The difference in the functions but symmetrical in the fenestration system at the same facade in Madrasa of Sultan Qalawun.

The facades opening within shallow or slightly geometric recesses became a remarkable style associated with Mamluks in all their building with many variations. However, the usual combination came to be recessed with a flat lintel decorated with several rows of stalactites. The recesses during the Mamluk period sometimes included a single window like in the Madrasa of Sarghitmish, Madrasa of Sultan Hassan, Madrasa of Um al-Sultan Sh‘aban. This single bay may also include a combination of two windows with a bull's eye like on the top-Qalawun set. In other cases, the two windows were included in one recess like in the Madrasa of Sultan Inaal and Madrasa of Qaytbay. Sometimes, the recess bay would include windows flanking the niche prayer and the bull's eye, like in the Madrasa of Sultan al-Ashraf Barsbay, or take the whole elevation to include all the windows like in the Madrasa of Amir Qijmas al-Ishaqi. In that the recess included the three arched windows with the windows below them and the recess was crowned by five rows of dropping stalactites. In almost all cases the qibla iwan and the mausoleum contain a mihrab[11] or prayer niche faces the street, usually the bull's eye was set over any mihrab. In the mausoleum the central area is covered by a large dome which admits generous amounts of light into the inside from its numerous opening and it rests always on four Muqarnas pendentives Fig. (2-15).

[11] **Mihrab** (pl. M*aharib*) is semicircular niche (architecture) in the wall of a mosque that indicates the Qibla; that is, the direction of the Ka‘ba in Makkah and hence the direction that Muslims should face when praying. The wall in which a Mihrab appears is thus the "Qibla wall".

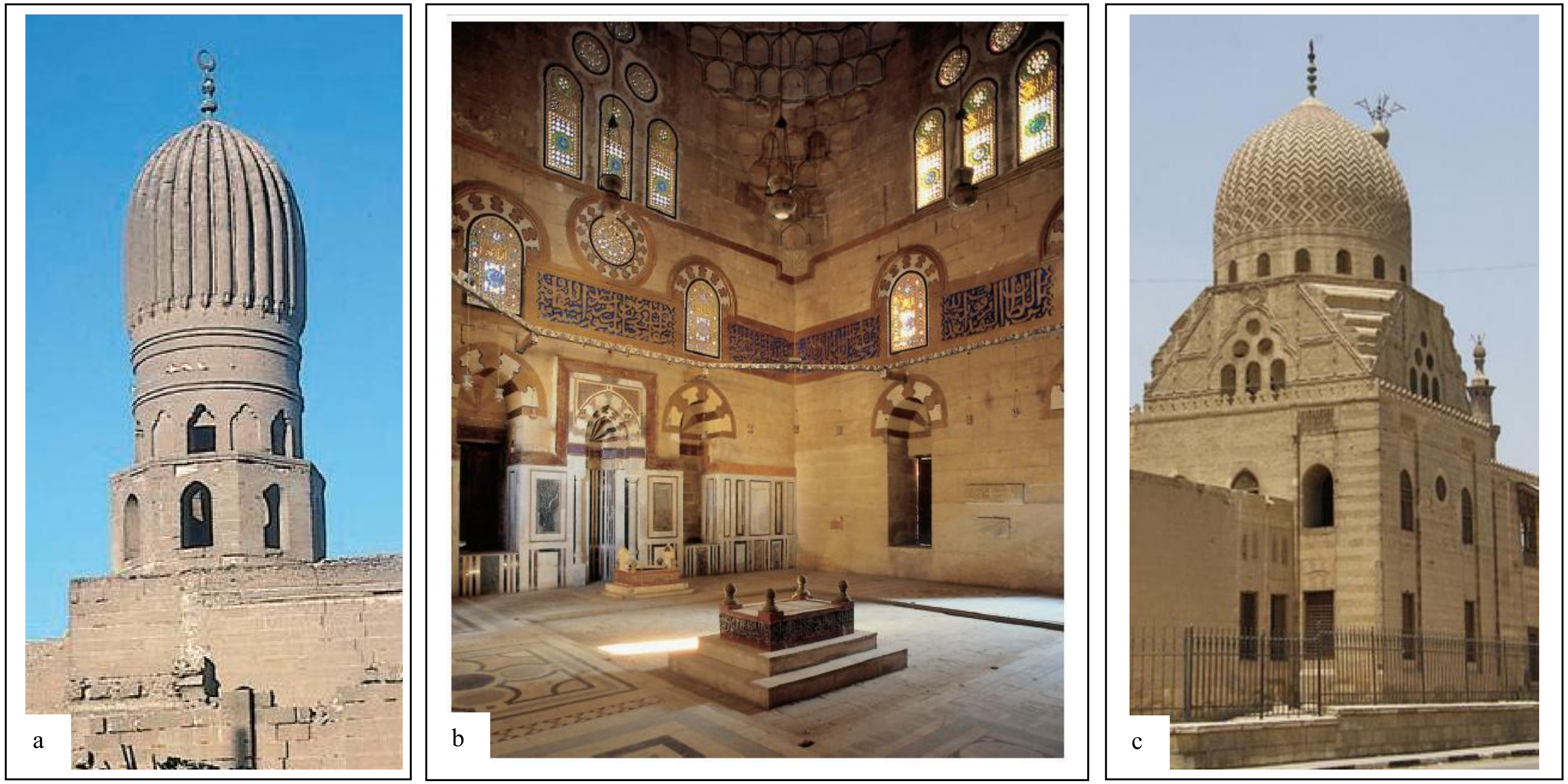

Figure 2-15: The fenestration system under the dome in the mausoleum space
a- Mausoleum of Amir Yunus al-Dawadar, b- One of the mausoleum chambers in the khanqah of Faraj ibn Barquq,
c- Mausoleum composition in Complex of Sultan Inal in northern cemetery.

The following table and figures show the different types of the geometric fenestration systems in Mamluk architecture by using an opening with shallow recesses in the building facades.

The facades opening within shallow or slightly geometric recesses	
Type	Examples
1- Recess with a flat lintel decorated with several rows of stalactites.	The door opening of mosque of Al-Aqmar (remains from the Fatimid period).
2- The recesses bay include a single window.	Mosque of Sarghtamish, Madrasa of Sultan Hassan (1356 A.D.), Madrasa of Um al-Sultan Shaban.
3- A single recess includes a combination of two windows with the bulls eye.	The top-facade in Madrasa of Sultan Qalawun (1285A.D.).
4- The two windows were included in one recess.	Madrasa of Sultan Inaal (1456A.D.) Madrasa of Qaytbay (1475A.D.).
5- Recess bay includes the windows flanking the prayer niche and the bulls-eye.	the Madrasa of Sultan al-Ashraf Barsbay (1432A.D.).
6- Recess bay takes the whole elevation to include all the windows.	Madrasa of Amir Qijmas al-Ishaqi (1479A.D.).
7- The bulls-eye was set over any Mihrab or prayer niche.	All buildings.

Table 2-2: Types of the fenestrations systems in Mamluk architecture

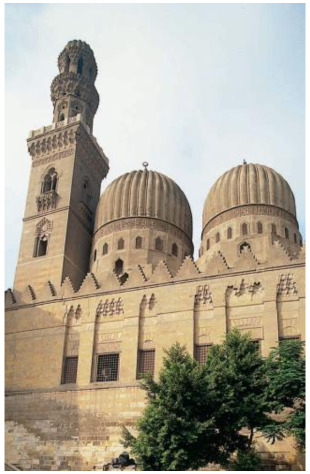


Figure 2-16: The recesses bay include a single window: The khanqah-Madrasa of Amir Salar and Sanjar al-Jawli

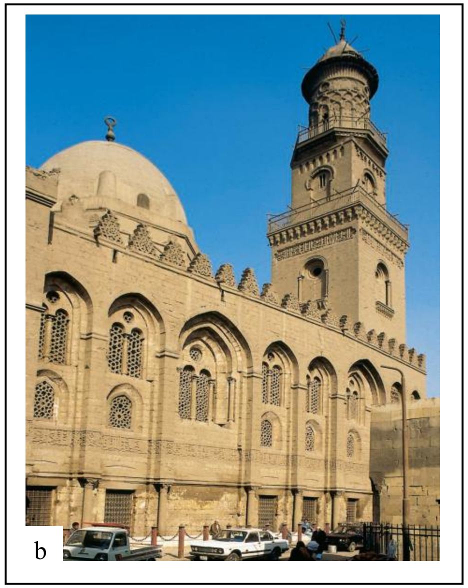

Figure 2-17 (a, b): A single recesses include a combination of two windows with the bulls eye:- Madrasa of Sultan Qalawun

Figure 2-18 (a, b): The two windows were included in one recess: a- Complex of Sultan Inal, b- Madrasa of Sultan Qaytbay

Figure 2-19: Recess bay includes the windows flanking the prayer niche and the bulls-eye in Madrasa of Sultan Barsbay

Figure 2-20: The bulls-eye was set over the mihrab or prayer niche in the Mosque of Aqsunqur.

2-19

2-20

2-21

Figure 2-21 Recess bay take the whole elevation to include all the windows in Mosque of Emir Qijmas al-Ishaqi

2.3.3.3. Mutual Relationship between the Layout and Planning

The growth of cities during the Mamluk period meant that most types of building were located within the fabric of a city. The result of this was that buildings were often built on an irregular-geometric-shaped plot because of the shortage of space. Many Mamluk buildings seeming to be geometrically regular are built on irregular ground plans. The architects were able to make the buildings appear regular by a variety of techniques such as horizontal lines (ablaq[12]) and passageways which distort perspective [Petersen,1999]p.173-174. Depending on geometry (geometric bases, principles and relations) is the hidden secret which explains the ability of the Mamluk designer to make the composition of these religious buildings geometrically regular despite the building sites being geometrically irregular.

The irregular building site: In Cairo, one of the most beautiful mosques of the Qaytbay period is erected by his amir, Qijmas al-Ishaqi (1478–9 A.D.). It is built on the triangular intersection of two streets, Shar'a Darb al-Ahmar and Shar'a Abu Huraybah. Because of the cramped nature of the site, the building design is very compact. The architecture of the mosque is due to the narrow shape of the plot of land on which it is built, which required the architect to separate the area for the ablutions, the bathrooms, the water trough for the animals and the primary school, and to locate them in another part of the narrow alley. He connected them to the mosque by means of an overhead bridge, so that movement in the alley would not be impeded [Yeomans,2006]p.226. This ingenious layout made optimal use of the plot. The mosque has four faces, the most important of which looks on Al-Darb Al-Ahmar Street; the architect was obliged to make some angles in this facade conform to the alignment of the street and to avoid hindering the free movement of pedestrians. The irregular plan of the mausoleum makes a striking impact as one approaches the building up Sharia Bab al-Wazir, the sharp, flange-like angles of the walls are echoed in the triangulation of the slanting planes that form the corner sections of the zone of transition, as shown on Fig.(2-22). This beautifully geometrically proportioned mosque provides a very good example of the ingenious geometric ways in which architects of the late Mamluk period adjusted the various architectural elements and spaces of a building to the available geometrically deformed building site.

[12] **Ablaq**: is a decorative technique indicating the alternating use of red and white or black and white stone in Islamic architecture (term used to describe alternating light and dark courses of masonry).

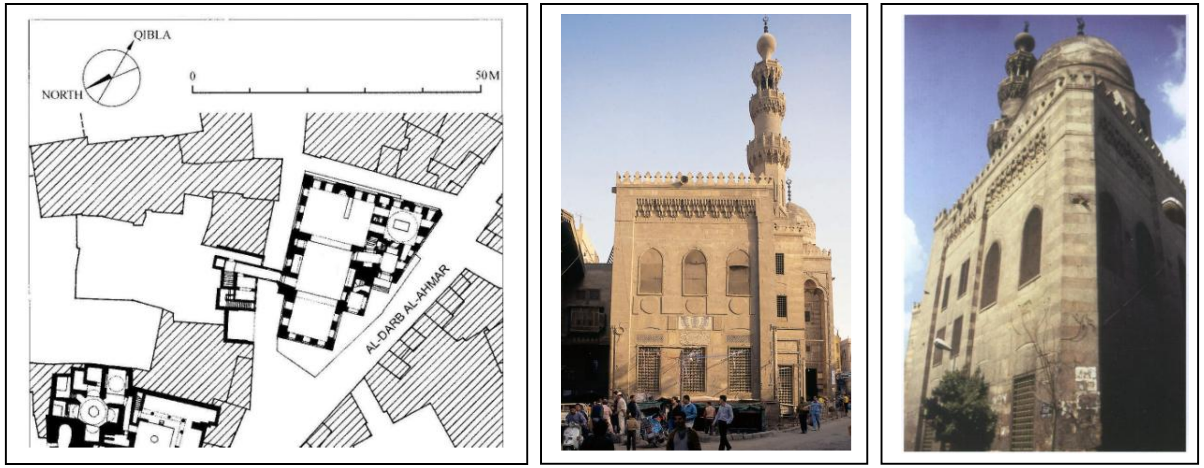

Figure 2-22: The mosque of Qijmas al-Ishaqi irregular site and the architectural treatments

Urban effect on building design: The geometric distribution of the visual elements (Portal, Dome and Minaret) inside the geometric composition of the building was mainly dependent on their mutual geometric relationship with the building surrounding's urban elements. For example, al-Ghuri Madrasa and Khanqah (1503–4 A.D.) are two imposing structures facing each other at the point where al-Mu'izz Street is crossed by al-Azhar Street. They form a geometric intersecting point causing a splendid visual climax geometric centre to the end of this section of the street. Also the case of Shaykhu the designer put the entrances of the building on the same geometric axis which connects the two parts of the building across the street, as shown in Fig. (2-23-24).

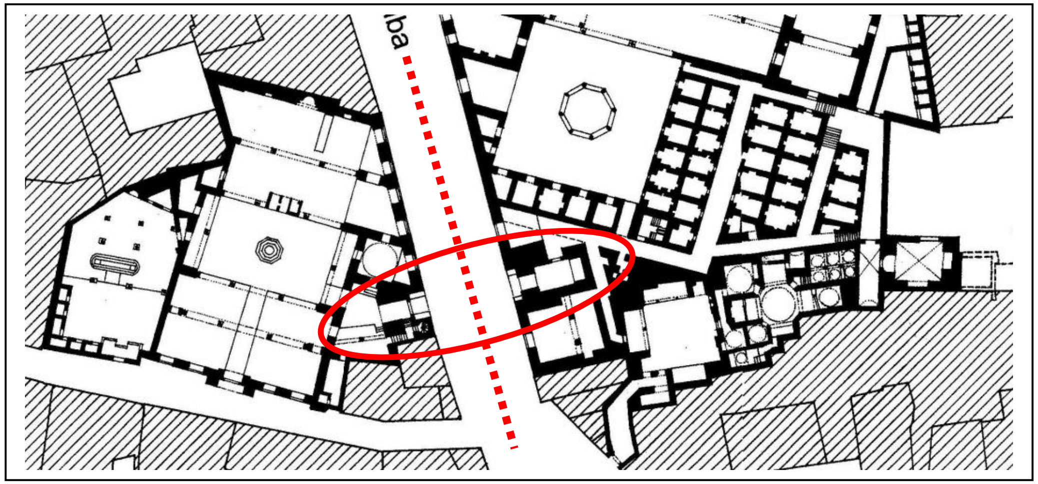

Figure 2-23: the distribution of the two parts of the Mosque and Khanqah of Shaykhu across the street.

Figure 2-24: Complex of Sultan al-Ghuri and its relation to the surrounding's urban context

2.3.3.4. Sophisticated Surfaces' Geometric Decoration

Decoration is a component of "architectural detail," along with moldings, color of fabric, texture, solids and voids [Scruton,1979]p.223. The role of decoration in a building's geometric composition either frames some parts in the building, such as openings, alcoves, transition zones, niche hoods, and so forth, or defines the separate parts of the construction besides emphasizing the important ones especially in the geometric composition of the facades. In our discussion of geometry, we referred to the existence of a primary grid that underlies all geometric decoration and remains visible. The primary grid, which assisted in the design and construction of the building, survived as an "after image" and became the starting point of all decoration [Golombek,1988]p.39-44. This hidden geometric grid takes the attention to think about if there are like these hidden grids used by the Mamluk architects to design their buildings in elevation as well as in plan.

Islamic geometric decoration pattern was constructed by a systematic arrangement of the repeat unit which produces the overall design [El-Said and Parman,1976]p.7. Geometry was employed as a method for mensuration and composition in all Mamluk geometric decoration design. The four basic geometric shapes, or "repeat units," from which the more complicated geometric decoration patterns are constructed are: circles and interlaced circles; squares or four-sided polygons; the ubiquitous star pattern; and multisided polygons. In each case, the designs display ingenuity through manipulating geometrically related background and foreground motif of different scale.

In the 14^{th} and 15^{th} centuries the ablaq technique became a characteristic feature of Mamluk architecture in Egypt, Syria and Palestine. At this stage red stone was also used so that some buildings are striped in three colors, red, black and white. [Petersen,1999]p.2. This was restricted to facades including the minaret, the portal and the interior as shown in Fig. (2-25).

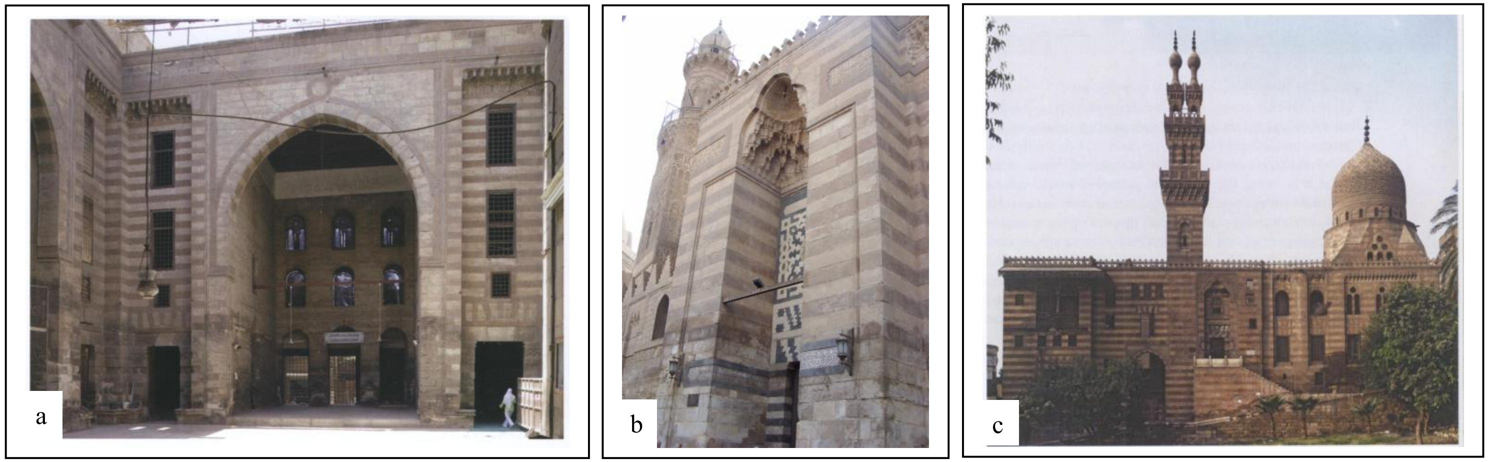

Figure 2-25 Using ablaq in the building decoration (the interior, the portal, the facade)
a- at the interior in Madrasa of Uljay al-Usufi, b- in the portal in Mosque of Mu'ayyad Shaykh, c- at the facades in Mosque of Emir Qanibay Qara

One of the sophisticated surfaces' geometric decorations is the mausoleum domed with its extraordinary geometric patterns, which are not just confined to the dome surfaces, but also appear on the cuboid structures that support them with all their varied facets, steps and undulations [Yeomans,2006]p.210. It is clear that geometry hidden in the complex decoration patterns, which was found on many objects, includes a number of different geometric shapes and arrangements, allowing these patterns to fit into more than one category of arrangements, as shown in the following figures.

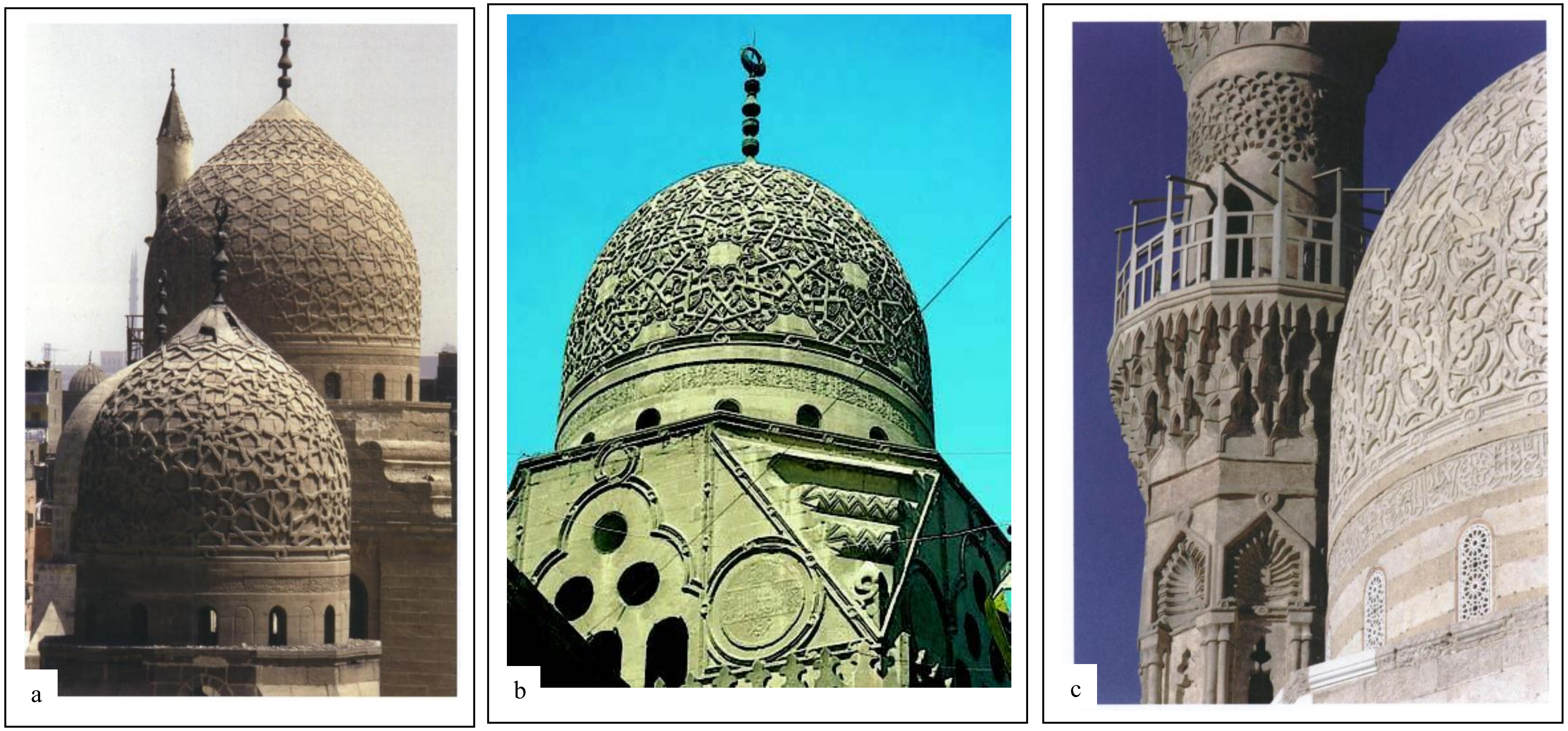

Figure 2-26 The geometric decoration in the surface of the dome
a- Domes of complex of Barsbay and Yashbak in the cemetery, b- Dome of Complex of Qaytbay, c- Dome and minaret of Mosque of Khayrbak

Not only the mausoleum dome but also the portal has high geometric decorative shapes. The most impressive masonry muqarnas of the Muslim world are found in some 14th century portals in Cairo. In the 15th century the use of muqarnas vaults diminished in portal architecture in favor of groined trilobe vaults resembling squinches. There is a parallel between portals vaults and dome architecture; the portal conch, being a semi-dome, was constructed to seem supported by muqarnas pendentives or squinches [Behrens-Abouseif,2007]p.89. This expresses the rich of the geometric vocabularies which the Mamluk architect played with them in his design, not only the architecture geometric composition but also the geometric decoration design in plan and elevations. The niche hood of the building gate as a known element in the Mamluk decorative vocabulary is shown in the following figures.

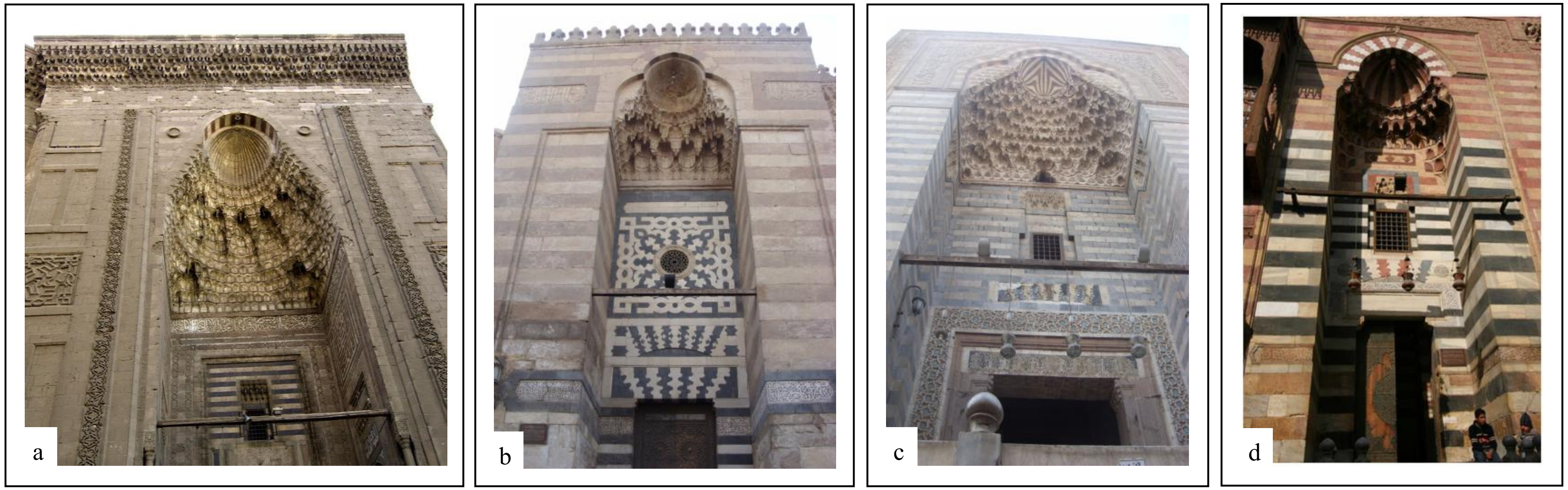

Figure 2-27 The niche hood of the building gate
a- Complex of Sultan Hassan, b- Complex of Sultan Barquq, c- Mosque of Sultan Mu'ayyad, d-Complex of Sultan al-Ashraf Barsbay.

2.3.3.5. Rich Variety of Designs and Tectonic Expressions

A simple examination of a range of Mamluk religious buildings reveals a discernible preference for geometrically ordered spaces. There was a tendency to organize spaces symmetrically around a central point.

The analysis of the religious architecture in the Bahirs Mamluk period shows that the design of the plan was based on the direction towards the inside, and that two patterns are predominant: The first is the courtyard surrounded by riwaqs; the second is the madrasa with four iwans surrounding a central courtyard [(OICC),1992]p.159. From the analysis of the religious architecture in the Burgi Mamluk period it is found that the plan is based on the introvert principle. It is noted that there are three patterns of plans: the first covers small mosques which, in addition to the mosque or madrasa, it also contains the sabil and kuttab and sometimes the mausoleum. The second pattern is the open courtyard surrounded by four iwans in the case of large mosques, madrasas or khanqahs. The third pattern, which is smaller in size, is composed of central durqa‘a[13]. Surrounding the durqa‘a would be two iwans, the south-east qibla iwan, and the north-west opposite iwan, and surrounding the durqa‘a would be two smaller side iwans (sadlah) [(OICC),1992]p.277. There are rich tectonic but the underlying geometric order remains consistently visible during the whole of the Mamluk era. This rich variety on the geometric composition of plan designs and tectonic expressions reveals two types of composition: concentric and linear.

1- Geometric concentric composition

The concentric composition represents all architectural designs that are laid out about a stationary centre, expressing the spatial-geometric order of the three-dimensional cross in a static manner. Two models typify spaces thus ordered: a centralized enclosed space and a centralized open courtyard.

The first form of the geometric concentric composition is the geometric centralized enclosed space which includes all architectural spaces that are defined by a geometrically regular base and domical, conical, or other form of centralized roofing. While the roof tends to emphasize unity and centrality, the base tends to emphasize the directionality [Akkach,2005]p.152. The simplest architectural embodiment of this model is a composition with a cubical base and a hemispherical dome, as the architectural composition of the Mamluk mausoleum.

The second form of the geometric concentric composition is the centralized open courtyard. It represents all confined, unroofed spaces that are organized symmetrically about a central point [Akkach,2005]p.155. The geometric order of this composition reveals the geometric proliferation of unity into quadrature. The defining surfaces are usually symmetrically articulated in relation to a central axis, leading to a balanced deployment of space in all directions. The open courtyard form is a major feature of many Mamluk religious buildings compositions. A geometric analysis of the plans of Mamluk madrasas show how the central space is distinguished in size and articulations from the other similar but smaller spaces, which nonetheless reveal the same underlying geometric-spatial order as the whole

2- Geometric linear composition

The geometric linear composition is created when the stationary geometric centre of a concentric space “moves”, manifesting through this motion a linear space that joins two or more points. In contrast to the concentric composition, the geometric linear composition represents all spaces that are focused by a “moving” centre, expressing the underlying geometric-spatial order in a dynamic way [Akkach,2005]p.157. Whereas the static unfolding of space in the geometric concentric composition reveals one centre in a pictorially unified space, the dynamic nature of the geometric linear composition manifests a multitude of centres, all of which are of more or less equal in importance.

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[13] The durqa'a is a covered sahn. The durqa’a is almost surrounded by two facing iwans, one larger than the other. The floor level of the two iwans is higher than that of the durqa’a. The durqa’a is surmounted by wooden dome or lantern which overtops the roof of the iwans. The durqa'a functioned as an entry space which gave access to the raised iwans. For more detail, see: Magda Sibley, Brian Edwards, Mohamad Hakmi, Peter Land “***Courtyard Housing: Past, Present and Future***”, Taylor & Francis, 2005.

2.3.3.6. The Reflection of the Function in the Geometric Form of the Plan and the Facade.

In Mamluk religious buildings there are many manifestations for the reflection of the function in geometric form of the building. That reflection leads to the emergence of many geometric features and architecture elements not only in the level of the building composition form and facade design but also extended to the urban context. The main geometric features in Mamluk religious architecture which are introduced as a result of the reflection of the space function on the building's geometric form are presented:

1- The Rise of the Monumentally Geometric Form

Due to the need for living quarters for the students in complex buildings in the Mamluk era, several floors were designed to accommodate their room, along with a kitchen (matbakh). This verticality inevitably gave rise to the monumentality forms. These rows of cells were accommodated on the leftover spaces of the internal facades of the courtyard or alternatively in annexed wings, and accessible from either the courtyard or from the entrance hall, in order to absorb the deformations from the building geometric form. In the urban context, Mamluk madrasa and mausoleum, which crowed the city's main axis, its importance to the pedestrians in the urban fabric is translated by the monumental facades which reflected the internal design in a manner that made it possible to distinguish the facade of a mausoleum from that of the madrasa.

2- The Introduction of the Four-Iwan Geometric Form

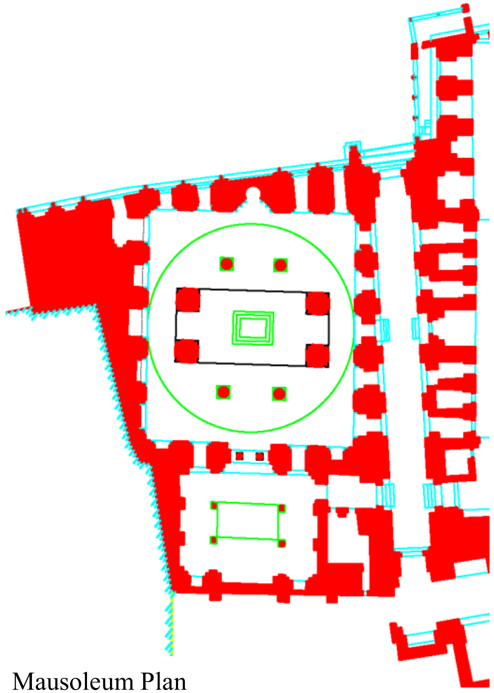
The need to accommodate space for the four schools of Islamic Jurisprudence (madhahib) as the cornerstone of the Islamic law resulted in the introduction of four iwans connected to the courtyard. The larger Qibla-oriented iwan was reserved for daily congregational prayer. The rise of the typical four iwans madrasa geometric plan as opposed to the pillared hall mosque rejects both the laterality of the praying hall and the lintel system of dividing the space[14].

3- The Emergence of the Mausoleum Geometric Form

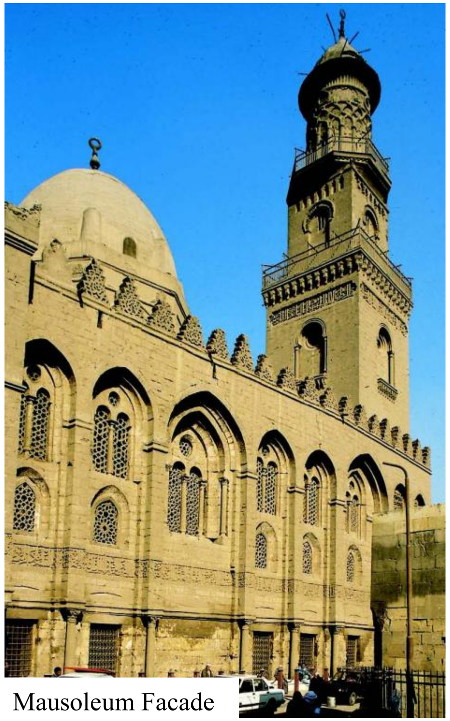
Mausoleums were a common feature of religious and semi-religious institutions from the early Mamluk period onwards. The mausoleum in itself is not a religious, but a secular building. By being attached to mosques, madrasas or khanqahs, and by traditionally having a prayer niche, it acquired religious features [Behrens-Abouseif,1989]p.104. These mausoleums were used as burying places for the patron or founder of the religious institution or for an important scientists ('alim) [Gabr,1992]p.139. The mausoleum's geometric form is always persistently emphasized between the building geometric compositions, so it takes the most prominent position of the building form on the main facade. The mausoleums vary greatly in geometric shape and scale; however, most of them are composed of a geometrically regular base with a domical or conical roof. One of the best examples of

[14] Some western orientalists of Islamic architecture advocate that the pattern of four iwans was taken from the crusaders design of churches which is incorrect. The fact remains that the main reason for making this design is to provide a place for gathering the four sunni branches of law in one area, although this pattern was also used in the madrasa grouping one or two Madhhabs, which was prevalent around Egypt since the 7th A.H. 13th A.D. until 10th A.H. beginning of the 16th A.D. (see: OICC: ***Principles of Architectural design and Urban Planning during different Islamic eras***, p.159).

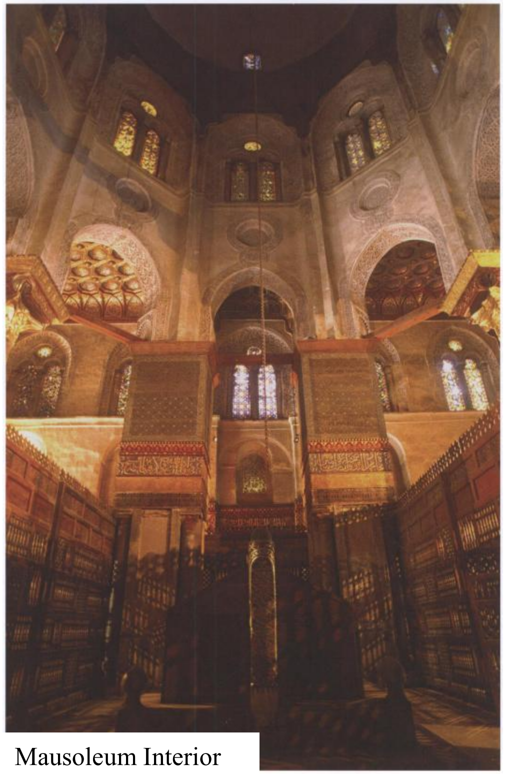
this is the mausoleum's geometric form in the Madrasa of Sultan Qalawun, which consists of a huge rectangular hall with a central dome supported on piers and massive columns.



Mausoleum Plan



Mausoleum Facade



Mausoleum Interior

Figure 2-28 : The geometric form of the mausoleum in Madrasa of Sultan Qalawun

4- The Emergence of Sabil-Kuttab Geometric Form

In most of the Mamluk religious buildings, the main facade is always flanked by two features known as sabil-kuttabs. These attractive two-storied structures consist of Qur'an schools placed over public fountains forming a uniform geometric unit in the building's composition. Such combinations became a feature of Mamluk architecture but they also appeared later, but rarely, as independent buildings[15], forming a distinctive art of Cairo's urban landscape. In Mamluk religious building, the Sabil is always

[15] It was Qaytbay who was responsible for the first free-standing Sabil-Kuttab in Cairo, built in 1479 A.D. See, Richard Yeomans, "***The art and Architecture of Islamic Cairo***" p.224

built into the corner of the building where the streets intersect adjacent to the main entrance [Mostafa,1991]p.90. The Qur'an schools are characterized by the open design of their windows and balconies, and the ground-floor sabils by their iron window grilles from which water was dispensed. Usually the sabil is placed in the corner of the building, and has two or three windows according to its location with relation to the surrounding streets.

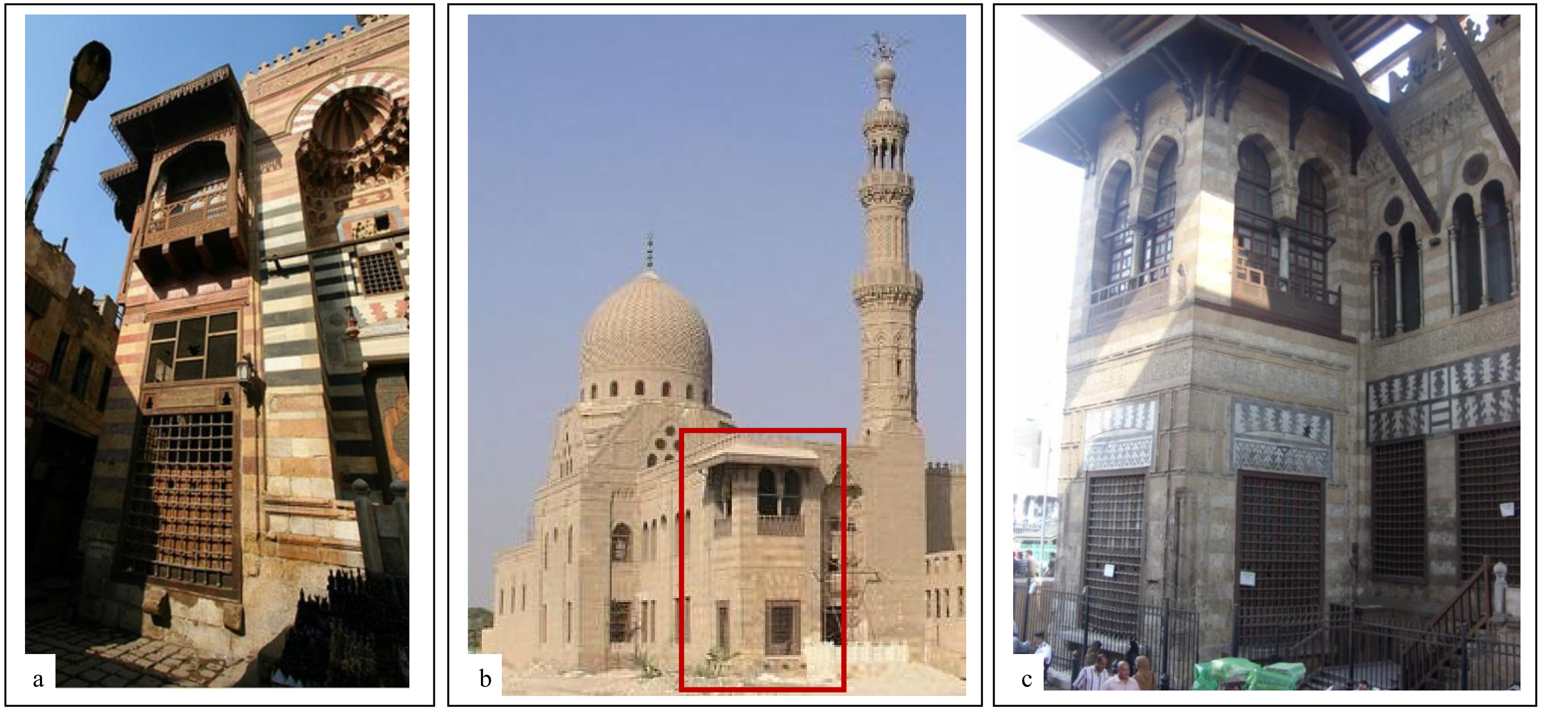


Figure 2-29 Sabil-Kuttab geometric form in Mamluk religious building composition
a- Madrasa of Sultan Barsbay, b- Madrasa of Sultan Qaytbay, c- Madrasa of Sultan al-Ghuri

2.3.3.7. Pure Geometric Expression of the Structural Elements

Structural elements such as columns, arches, domes, wooden roofs, vaults, (stucco, wood and metal grilles) on openings, staircases, all these structural elements, could be seen in pure geometric shapes in building composition and facade design.

The pure geometric expression of the structural elements can be seen clearly on the dome composition. Domes especially were common in buildings of the Mamluk period and could be made from a variety of materials including baked brick, wood and stone. There are two types of dome, regarding the method of transition from the square plan into the circle, the dome rested on four squinches in the corners of the square and the dome rested on spherical pendentives [Ibrahim,1975]p.9. Domes in which the square plan is transformed into a polygon and consequently into a circle through squinches, squinch rows gradually increased, we find three rows in al-Salih Nagm al-Din Dome (1249-1250 A.D.), four rows in the dome of Baybars al-Gashankir Khanqah (1306-1310 A.D.), five rows in al-Nasir Muhammad Mosque (1335 A.D.), and nine rows in the dome covering the tomb in al-Nasir Farag ibn Barquq Khanqah (1401 A.D.). Stalactites (muqarnas) were used later on as a structural element in transforming the square plan into a circle. The stalactite consists of many rows and every row consists of a number of niches. This expresses how the Mamluk architect could use the different geometric shapes in these structural elements composition.

These geometric features, and many others, characterize Mamluk architecture and contribute to its seldom-used style. These features helped the Mamluk architect to produce his geometric conceptual design for his city in general and his building in particular. These features are the main factors with which the Mamluks could form the language of Cairo architecture and produce their architectural masterpiece.

2.4. The Mamluk Educational System

"Search for knowledge ('ilm) even unto China, because it is an obligatory duty of every Muslim" [Ibn'Abd.al-Barr,1925]p.7.
"There is no work better than the pursuit of knowledge, if it is for the sake of God alone" [Ibn'Abd.al-Barr,1925]p.25.
"The men of learning ('ulamã') are the trustees of God in the land" [Ibn'Abd.al-Barr,1925]p.52.

As seen in these three authentic Prophetic ḣadĩths, to ask for knowledge (ṫalab al-'ilm) in Islam is highly esteemed and classed at a superior level above all types of worship ('ibãdah). It is for this reason that so many patrons have sponsored educational institutions through out the different periods of Islamic civilization [Gabr,1992]p.17. The willingness of the Mamluks to be closer to their people was one of the reasons that led to the boom of education at the Mamluk era. Mosques were founded for the people of religion, and schools for learners, and the Zawaiaa for the poor people and khanqahs for the Sufi devotees. As a result of the high interest in the construction of educational institutions, and to meet the spending needs of these institutions so they would be able to carry out their functions fully and continuously, the endowments (Waqf[16]), which play the role of financial support for these educational institutions, reached a saw an increase.

In order to understand the architecture education in the Mamluk era and how it could introduce professional architects to society, the following section demonstrates the architectural education, through presenting its stages, its institutions and its curriculum, as shown in the following chart.

[16] **Waqf** [ˈwæqf ; plural awqāf) is an inalienable religious endowment in Islamic law, typically denoting a building or plot of land for Muslim religious or charitable purposes, while a person making such dedication is known as Waqif.

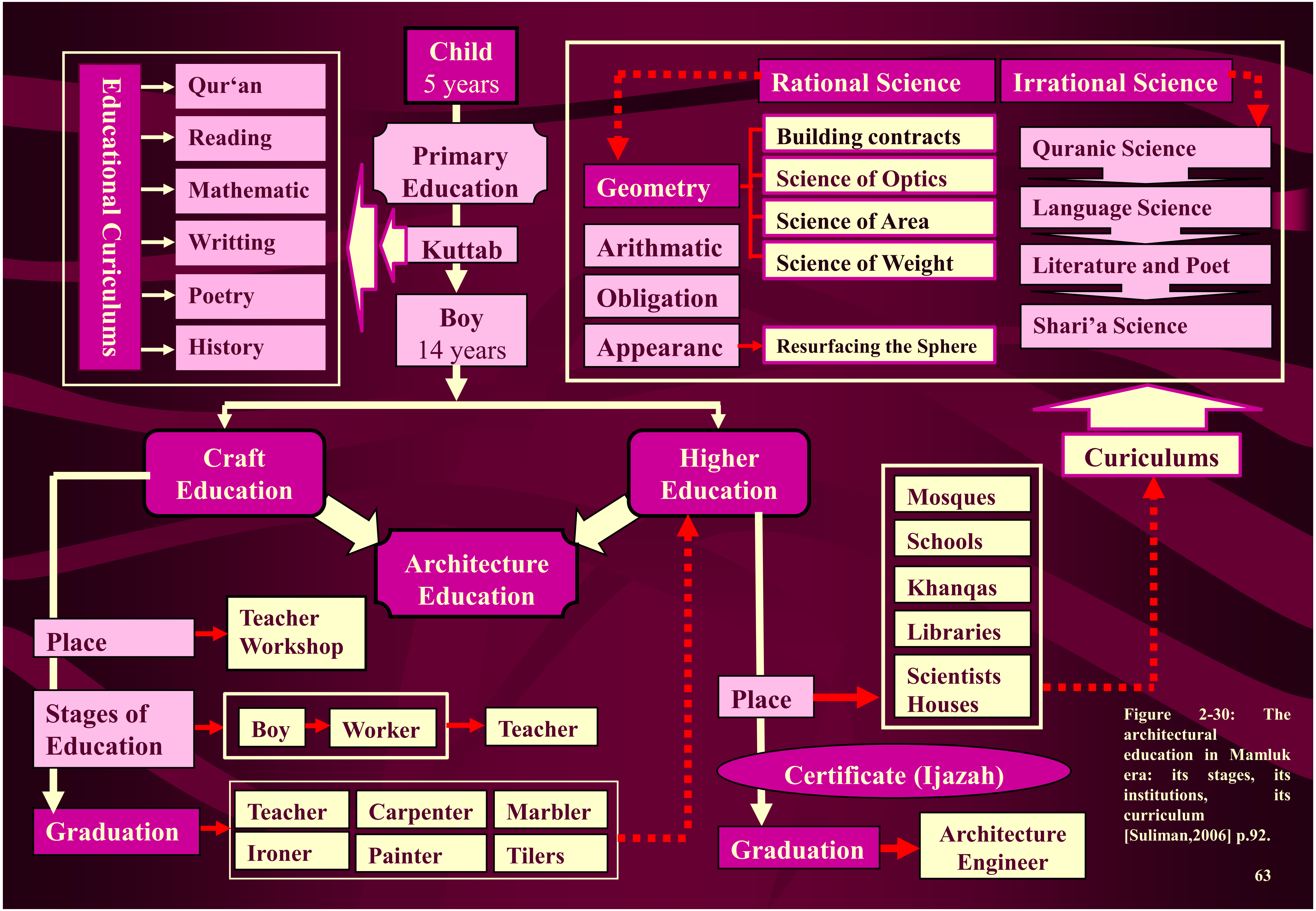


Figure 2-30: The architectural education in Mamluk era: its stages, its institutions, its curriculum [Suliman,2006] p.92.

2.4.1. Educational Institutions

Educational institutions varied greatly during the Mamluk era. All the institutions played two roles at the same time: the educational role alongside the religious role. This section deals not only with educational institutions which were suitable for architects, but also those in charge of building construction and the architects admitted with them to complete their education.

The educational system can be divided into the primary education (first stage) which depends on the kuttabs (singular kuttab) as the main institution for that level of education, and the higher education (second stage) which depends on three main educational institutions, which are the schools (madrasa), libraries (maktaba), Mosques (jamĩ or masjĩd). Besides these three main institutions there are others for that level of education such as the book market (Suq al-Kutub), khanqahs, scientific councils (Magalĩs al-'ilm) and the homes of scientists (Manazl al-'Ulamã'), as shown in Fig. (2-31). The four main educational institutions, their role in the preparation of the architects, and how they could produce the professional architects from society are shown here:

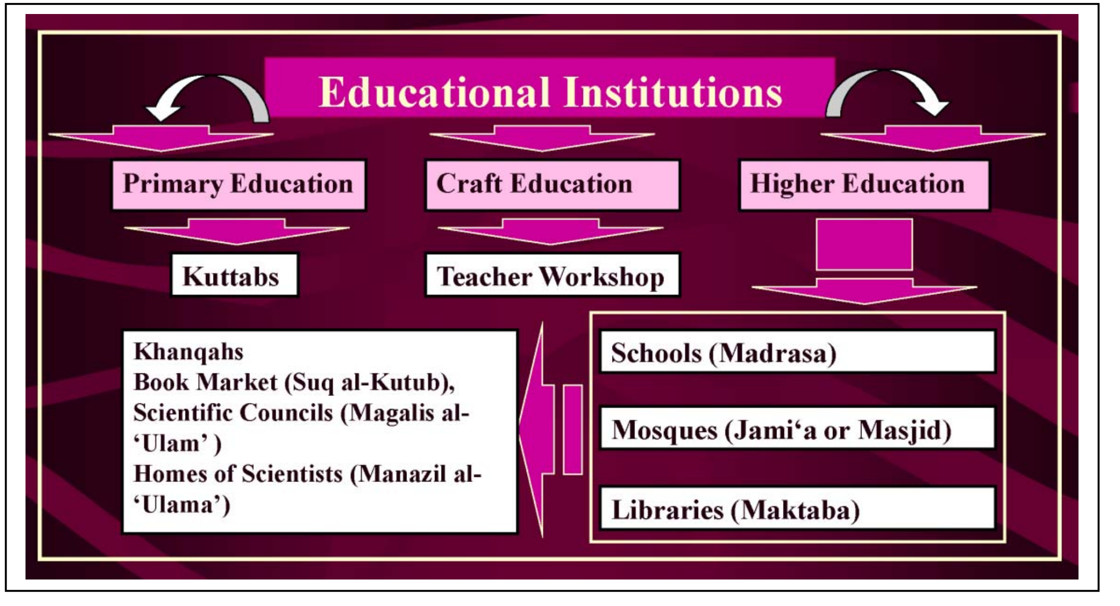


Figure 2-31: The educational institutions in the Mamluk era.

2.4.1.1. Kuttabs

There are two types of kuttabs that emerged in the Mamluk era for the primary education. They introduced the same educational aim. They are as follows:

The private kuttab: the private kuttabs were subsidised by individuals, who took education as a profession in order to earn money, so they were attended by all those who wished to learn but after the payment of expenses.
The public kuttab: the public kuttabs were held by sultans and amirs in order to appeal to God Almighty, so education was free for orphans and the poor.

Architecture of Mamluk period has been distinguished by the grouping of the sabil and kuttab in one block attached to the educational institutes, such as mosques or schools or khanqas, or in an independent building. On top of the sabil would be the kuttab, with its facade as a wooden balcony with arches, topped by a projecting roof leaning downwards.

The position of establishing the public kuttabs, when they were attached to educational institutions was selected with high accuracy. As shown in the following figures, the position of the kuttab took an important location in the building design. As can be seen in many buildings in the Mamluk era it always took the corner of the building.

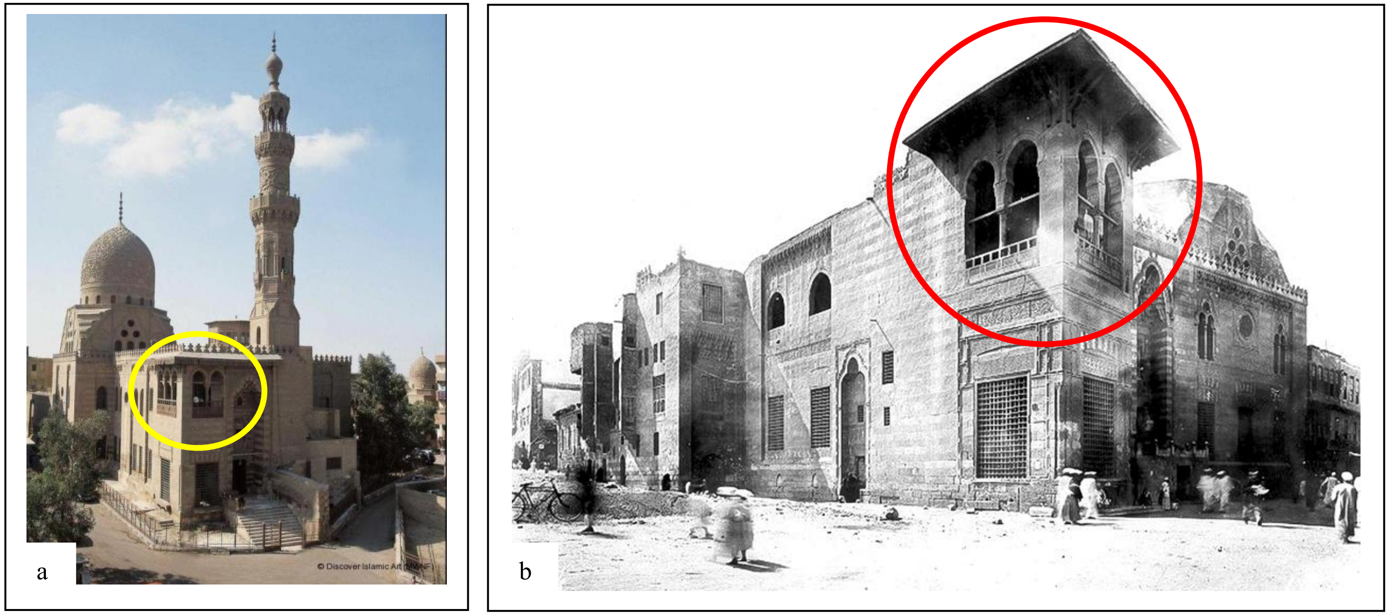


Figure 2-32: The position of the kuttab in the composition of Madrasa buildings: a- Madrasa of Sultan Qaytbay, b- Madrasa of Sultan al-Ghuri.

2.4.1.2. Schools (Madrasas)

The Mamluk sultans followed their precedent the Ayyubid sultans in the same educational system, so they constructed numerous schools (madrasas). The sultans wanted to be beside the men of religion (‘ulamã’) through these schools, also in order to preserve their names through time in Egypt by the establishment of such schools. Ibn Battutah, the medieval traveller (779 A.H., 1377 A.D.) accordingly wrote that the madrasas of Cairo could not be counted because they were so numerous [Ibn-Battũtah,1880]p.70. The Mamluk rulers embarked on a campaign aiming at building a number of madrasas in Cairo and in the short period of forty years, about twenty madrasas were built in Cairo alone [Al-Maqrĩzĩ,reprint 1998]Pp.363-368.

The school was characterized with an open educational system. It had not provided its services only to the students there, but also to the public who wanted to attend classes or have access to books and see the literature and collectables in the library [Osman,2000]p.115. Schools served as institutes of higher education, like universities today. Each school was allotted a number of teachers, students and employees, and a large bookcase. At these schools a rich endowments were provided to ensure students and teachers a degree of quiet life in order to make them concentrate on learning [‘Ãshũr,1996]p.227.

Inside the madrasa students lived and prayed as well as studied, so the building design tended to combine the features of both domestic and religious architecture. As religious architecture, they had to be oriented in their interior to Makkah. They were also built with minarets in order to be suitable for holding the Friday congregational prayers. As a domestic architecture, they had living units as well as incorporating baths (hammãmat).

2.4.1.3. Libraries or Bookcase (Maktabat)

An important pillar of scientific activity at any time and place is books and libraries. Without books and libraries, the educational institutions cannot play their role and realize their mission. Because of the great scientific activity in the Mamluk period, there was unprecedented activity in authorship, on one hand, and in the collection of books and construction of great libraries, on the other [‘Ãshũr,1976]p.345. Therefore, school and mosque libraries in the Mamluk period had an extraordinary degree of order and wealth of references in various sciences and arts.

The Mamluk sultans took care of literature as well as wrote books and collected rare manuscripts. They established and constructed all types of libraries[17] mainly to preserve the books and the old manuscripts [Al-Nashar,1993]p.109. Their desire was that students and scholars should benefit from those books, especially because books were expensive at that time. As printing was not known back then, the only way to obtain a particular book was to copy it by hand. This was an expensive and difficult profession; therefore, access to a copy of any book was beyond the reach of the ordinary man.

It was a custom to attach a library to the educational institutions to house the most important sources of different kinds of knowledge, and to introduce services, for example, the internal reading and copying services; some libraries provided an outside book-borrowing service, and other services (like providing students with different materials (paper, pens and ink), besides holding lessons, lectures and discussions) [Al-Nashar,1993]p.201. These libraries played an important role in securing access to

[17] In the Mamluk eras many different types of libraries could be seen in Cairo, such as private libraries, mosque libraries, madrasa libraries, Bimaristan libraries, Zawaya and khanqahs libraries and also mausoleum and dome libraries. For more details see, Al-Sayd Al-Sayd Al-Nashar, ***Tarikh Al-Maktabat fi Misr: Al ‘Asr Al-Mamluky***, ed.1, 1993, Chapter 1.

the books and manuscripts which students were required to read. This saved students and lovers of culture a great deal of money which they would have had to pay to copy the books they needed.

Libraries or bookcases in the era of the Mamluks were not attached only to schools, but also to the khanqs and mosques in order to reach the aimed scientific benefit. In all cases the bookcases were maintained by the "Treasurer of books", as a librarian to take charge of the affairs of the library. His role was the arrangement, maintenance and the repair of books from time to time [‘Ãshũr,1992]p.146, as well as maintaining a reader’s guide to what people need from references. Therefore, he had to possess high scientific knowledge and honesty. Libraries were appropriately situated in these institutions – for example, between the four iwans in the Mamluk madrasa – in order to provide them with easy access. Fig. (2-33) shows the position of the library or bookcase within the building.

The Mamluk endowments’ documents showed that the books could only be borrowed for use inside the schools. Outside borrowing was largely restricted and allowed only when there were multiple copies of the book or the book was not required by anyone at a certain time, often for school students and scientists (‘ulama’) [Al-Nabbahĩn,1981]p.280, These restrictions in the book-borrowing process were for the protection of the books to keep them from being damaged and getting lost, as well as avoiding delays in bringing the books back.

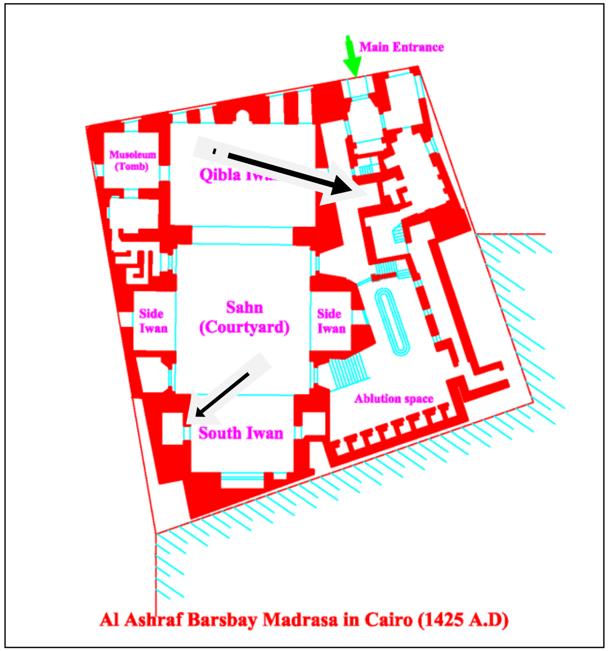


Figure 2-33: The position of the bookcase inside the Madrasa of Sultan Barsbay

2.4.1.4. Mosques (Jamie or Masjid)

The mosque was the only educational institution up to the Ayyubid period. Then the madrasa as the second educational institute was brought to Egypt with the Ayyubid Sultãn Salãh al-Din al-Ayyubĩ when he conquered Egypt. In the Mamluk period the madrasa became a successful way to fulfil both the educational as well as the religious requirements.

There was also book market (Suq al-Kutub) besides the previously four main educational institutes. It was not used only for buying books and paper but also as a cultural centre, where all of the scientists met and many discussion circles were formed. Besides the book market there were also the khanqahs which were established to provide the Sufis with a home, a place of worship and a place for their essential needs. There were also the scientific councils (Magalis al-‘ilm) and also the homes of scientists (Manazil al-‘ulamã’), which were provided especially for scientists when they were very old and their health prevented them from travelling to the education institutions.

2.4.2. Teaching Methods

Two types of teaching method are introduced; the first is used in the higher-education institutions such as schools or mosques and the second is used in the crafts education in the Mamluk era.

2.4.2.1. The Teaching Method in the Higher-Educational Institutions

The process and method of teaching in the Mamluk higher-educational institutions was done in a circle (halaqah or dars) in both mosques and madrasas. In these circles the teacher (mu’allim) would sit facing the qibla (the direction of prayer), and the students sat around him. The lesson was divided into three sections [Ibn-Battũtah,1880]Pp.38-45:-

The first was the beginning in which the teacher (mu’allim) would read a part or more from the Qur’ãn.

The second was the middle in which the teacher would start his lesson.

The third was the end in which the teacher would ask a few of his students would repeat what they had heard to make sure that it had been understood.

In case that they had misunderstood, the teacher’s assistant (mu‘ĩd) would repeat the lesson again.

It can be concluded the teaching methods in the Mamluk educational system depended on a system of apprenticeship, capable of introducing a scholar who was able to faithfully transmit the knowledge they had learnt, without forgetting that this traditional system of oral transmission traced back to the earliest centuries of Islam.

2.4.2.2. The Teaching Method in Craft Education

The Muslims emphasized the craft education which the students enrolled after the first stage of education. It is a kind of education which holds and is based on the process of indoctrination as well as training and acquisition of skills on the basis of knowledge and scientific principles. This craft education is equal to the practical training for the architects [Al-Hinady,2000]p.106. Each craft had a Sheikh (supervisor or the chief of the craft) [Mubarak,1885]p.100, elected by the craft teachers for one year but which could be renewed. The Sheikh must be superior in three branches of knowledge: unification science, religion science and craft industry science.

The craft education stages can be divided into three stages, according to the hierarchical rank of craftsman inside the craft society, beginning with the training stage and ending with the teacher’s stage. The manufacturer stage is the intermediate stage.

In these stages the craftsman thought about the craft rules, principles and basis with the help of a learning process which is a training process.

1- Training Stage (Boy Stage: Saby)

The boy enrolled with a teacher whose craft he wanted to learn and then lived with the teacher. For every teacher there was a certain number of boys, who he thought. The teacher could refuse to teach any boy, whom he considered incompetent at exercising the craft. The teacher did not pay them and they did not have any rights either. The training period for each craft was around seven years, during which the teacher trained the boy and assessed the degree of his progress [‘Amer,1993]p.36.

After the boy had finished his training period, the craft Sheikh examined him. This examination was conducted to decide whether the boy was fit to pass to the next education stage in the craft community or not. The boy could not attend any other teacher’s classes if he left his teacher. He could only return to his craft Sheikh to move from one teacher to another [Husien,1987]p.50.

2- Worker Stage (Manufacturer: Sani‘ or ‘Ariyf)

It is the intermediate stage between the boy’s stage and the teacher’s stage. In that stage, the worker made a contract with his teacher. According to this contract the teacher housed and fed the boys besides paying them for their work. The working period ranged between 3-5 years. During this period the manufacturer could not leave his teacher before the end of the specified period [‘Amer,1993]p.38.

The graduation from the worker’s stage to the teacher’s stage could not be done randomly, but only after the testing of the manufacturer’s skills and his degree of professionalism in the craft’s rules and basis. This test was carried out in order to maintain the craft and differentiate the quality of work and to guarantee that the profession would not vanish because of a lower-skilled workforce [Nawar,1985]p.221.

3- Teacher Stage (Mua‘lim or Ousta)

The transition to that stage required getting the license (Ijazah), which grants permission to practice the craft [Mubarak,1885]p.101. That permission was the last thing received by a person in the craft education which enabled them to practise the craft thereafter.

After finishing the three stages of craft education and becoming a craft teacher, the option was open to the person to continue his education in the higher-educational institutions. In other words, at the end of the learning process of craft details and basis from the teacher, it was possible to continue to a higher education level in order to improve the level of professionalism of the craft. For example, Abu al-Wafa al-Buzganĩ, the famous Mamluk engineer who was a craftsman and went to Iraq to learn the geometry science [Tĩmour,1957]p.27. He made many additions to the geometry science. He released a book called “On the geometry needed by craftsman”, in which he demonstrated the link between craft and geometry science.

2.4.3. Teaching Staff and Students

In the Mamluk educational system, teaching staff included scientists (‘Ulamã’: who were the teachers) and teacher’s assistant (mu‘ĩd) and the student. The question which arises is whether there was an engineer (builder) among these teachers. And was he trained in anything besides teaching? By reading the manuscripts it was discovered that there were many engineers who worked as teachers, and that many geometric works of buildings and art were assigned to them. This reflects and explains a high role and effect of geometry in building design and construction and how it helped them to generate this genus style [Tĩmour,1957]p.5-11.

The students enjoyed the freedom to choose their study materials and to select their teacher. Often this choice depended on the teacher’s scientific reputation. For students, this education was not only free, but they were also ensured financial charge, housing and clothing, as well as the cash given to them every month and, the amount of which was according to the endowment document [‘Ãshũr,1992] Pp.161-164.

Mamluk sources refer in more than one case to the relationship between a student and his teacher. This is described as one of deep respect which continues even after the death of the teacher. Ibn Jamã‘a said that “a student would visit the grave of his teacher, ask for his forgiveness, and would give money to the poor in his name (sadaqah), and take care of his children and relatives for him.” [Gabr,1992]p.20. In spite of this deep respect for their teachers, students could decide who they saw as being fit or unfit to teach.

In the Mamluk era the so-called craft inheritance emerged, which means the son practices his father's profession. The craft inheritance was a result of the learning associated with the workplace and the desire of parents to maintain their wealth and continue their shops. An example of such inheritance and proliferation of professional craft in a particular family is the family of Ibn-Al-Tulunĩ known by many for its engineering work. The progress of the stonecutters and the builders in Egypt was related to it [Tĩmour,1957]p.58.

2.4.4. Financial Resources

The only Muslim institution which combined certain aspects of royal patronage, religious domain and civic functions was the establishment of religious endowment (waqf, plural: awqaf). This was based on pious donations by the powerful and the wealthy, which were given for a social purpose and became forever the inalienable property of the community, administered by the kadi. These donations could consist of funds to build and/or maintain social welfare buildings such as mosques, schools, baths and fountains (which were sometimes combined with the tomb of the sponsor). Or they could consist of land, commercial facilities or houses, the returns from which were allocated to social welfare purposes. Since they were inalienable and could accumulate over centuries, Waqf properties eventually covered large parts of urban real estate. In practice, the institution of the Waqf thus provided the public funds which were needed to finance and to run the public domain of Islamic cities. It also strengthened the role of the kadi as the responsible representative of the community, especially vis-a-vis the ruler, who was not entitled to use the accumulated funds for his own purposes [Bianca,2000]p.28.

The endowments documents can be defined as follows: they were contracts determining the endower's requirements to the institution he worshiped. These documents were not intended as a historical record, but rather only to record conditions, rules and requirements of endowment. However, over time they became, unwittingly, a reflection of the vision of that time and its scientific, educational, religious and social activities. Waqf documents constitute, at least potentially, the most valuable single type of material for the study of architecture. This is because they frequently contain not only descriptions of specific monuments, but also stipulations defining in the most precise detail the types of activities which were to take place within the confines of these monuments. In other words, they provide a means by which not only the broad outlines of function can be postulated, but even the most minute and concrete details of those who lived within a foundation can be ascertained. As such they not only the potential to enhance our understanding of the particular monuments and institutions for which they were erected, but are also an analogy and generalization which provide insights into the functional specifics of Mamluk architecture as a whole [Alhamzah,2009]p.19. Through that, these documents are closer to the truth and the expression of the historical reality than has been written within them.

The educational institutions in the Mamluk period received a fixed income which enabled them to perform their mission and strengthen their system. The spending on the educational process came from the endowments allocated to these institutions. As it was customary for the Mamluk sultan to build those institutions and determine the endowments such as agricultural land houses, markets and others, and he spent these land proceeds on these institutions' educational and charitable activities, more precisely on the institution and its staff teachers and students of science. In the Mamluk era the educational institutions were widely spread (schools, mosques, khanqahs and many others). In these institutions the students were educated; thus the libraries attached to these institutions were provided with all the required books.

2.4.5. Educational Curriculum

According to Tãj al-Dĩn al-Subkĩ [Al-Subkĩ,reprint 1948]p.67-101, and Hajjĩ Khalĩfah [Hajjĩ-Khalĩfah,1941], two Mamluk writers, the sciences in the Mamluk educational system were divided into three main branches:

The main branches	The sub-branches
1- Sharĩ'a oriented science (al-'ulũm al Shar'iyyah)	a- Jurisprudence (Fiqh). b- Sources of jurisprudence (Usũl al-fiqh). c- Qur'ãnic interpretation (Tafsĩr). d- Prophetic traditions ('ilm al-hadĩth). e- Science of Qur'ãnic recitation ('ilm al-qirã'ãt).
2- Arabic language oriental science ('ulũm al-lughat al-'Arabiyyah)	a- Nahw (Grammer). b- Sarf and bayãn (Conjuagation).
3- The rational science	a- Medicine ('ilm al-tibb).

(al-‘ulũm al ‘aqliyyah)	b- Arithmatic (‘ilm al-‘adad). c- Algebra (‘ilm al-jabr). d- Geometry (‘ilm al-handasah). e- Cosmology (‘ilm al-hay’ah). f- Temporal (‘ilm al-mĩqãt). g- Physics- literally “nature” (‘ilm al-tabĩ‘ah). h- Alchemy (‘ilm al-kĩmyã).

Table 2-3 The educational curriculum in the Mamluk educational system

In his “Muqaddimah[18]” Ibn Khaldũn explicitly states: “the sciences and the crafts are treated as one”[Ibn-Khaldũn], which means that the sciences that were taught in Mamluk educational institutes were connected to the sources of knowledge (‘ilm) that were passed on in the course of instruction in the crafts, amongst which is architecture.

S’aid ‘Ãshũr, the contemporary historian who has written a great deal on the Mamluk period, confirms that the crafts in the Mamluk period were acquired through a system of apprenticeship. He says: “Guild’s (niqãbãt) in the Mamluk period were based on apprenticeship.” [‘Ãshũr,1959]p.207. This is confirmed by al-Maqrĩzĩ’s (845 A.H., 1442 A.D) accounts of when he passed through the papers market (sũq al-warrãqĩn): “under the hands of each master (Mu‘allim) several young boys were working under his instructions” [Al-Maqrĩzĩ,reprint 1998]p.569. He further elaborates saying “every craft in Egypt had an ‘arif, one who help the master in supervising the apprentices of his craft.”. This confirms Ibn Khaldũn’s point of view concerning the crafts and science being treated as one - i.e., following the same system of indoctrination.

From all these subjects the science of geometry is discussed in detail by presenting its types and its main branches, because it is one of the main sciences which the Mamluk architect depended on for the design of buildings. The Mamluk architect had to be proficient in them in order to practice the craft of building.

2.4.5.1. Science of Geometry

Al-Fārābi[19] classified this science into two types: applied and theoretical geometry [Al-Fārābi,reprint 1996]p.51

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[18] The **Muqaddimah** meaning in English: Introduction to Universal History, also known as the **Muqaddimah of Ibn Khaldun** or the Prolegomena, is a book written by the North African historian Ibn Khaldun in 1377 A.D. which records an early view of universal history. Some modern thinkers view it as the first work dealing with the philosophy of history or the social sciences of sociology and cultural history. Ibn Khaldun wrote the work in 1377 as the preface or first book of his planned world history, the Kitab al-Ibar (lit. Book of Advice), but already in his lifetime it became regarded as an independent work.

[19] ***Abū Nasr Muhammad al-Fārābi***; known in the West as Alpharabius (259-339 AH / 870-950 AD), was a Khorasani polymath and one of the greatest scientists and philosophers of Persia and the Islamic world in his time. He was also a cosmologist, logician, musician, psychologist and sociologist.

1- Applied geometry is a geometric science, which deals with geometric shapes and their properties, and with those properties practically according to each craft, like the wall for a builder or the wood for a carpenter, he says:

> "applied geometry is that which considers the lines and surfaces of a wood body when the craftsman is a carpenter, or in a wall body when the craftsman is a builder; like every craftsman of applied geometry, he is portraying inside himself lines, surfaces, squarely, cycling and triangulation in the body of the material which is set for that applied industry"

2- Theoretical geometry is a geometric science which is applied regardless the type of the used body material, as he says:-

> "theoretical geometry science is that which considers the lines and surfaces of the objects as a whole ….so the craftsman portrays lines in a public phase, regardless of the body they will form"

According to Al-Fārābi classification, the study of geometry can be divided to two types:

* The first type deals with the study of lines and surfaces and their relationship to each other and the study of angles and areas, so it can be defined as follows: " it is a science from which one can know the phases of the amounts and their accessories and the position of each one to the others, and its proportions besides the properties of its shapes. Its matter is the absolute amounts like lines and surfaces, and the accessories of this like angles, points and shapes."[Tash.Kubrĩ.Zadah,1985]p.347.

* The second type deals with solids (cubic, cylinder, prism and cone) and is divided according to the type of solids into two types: One studies each of the solids separately, but the other studies and considers the solids' relationships, especially the relationships which come out when they are added to each other or they are arranged alongside each other in one collection [Al-Fārābi,reprint 1996] p.53.

2.4.5.2. Branches of Geometry

There are many types of geometry such as descriptive, analytic, axiomatic and modern geometry. In this section, branches of geometry which were helping the Mamluk architect in constructing and decorating his buildings are demonstrated.

1- Science of Building Contracts.

This science deals with the conditions and the status of the building, how to maintain and preserve them, and the methods of decorating them, such as building the forts and constructing the beautiful buildings. The great benefit of this science is in building cities, houses and castles [Tash.Kubrĩ.Zadah,1985]p.352.

2- Science of Optics.

This science deals with the study of objects from the visual aspects' point of view, and the objects' different positions in terms of the nearest and furthest, and the highest and lowest from the eye of the beholder.

This science helps in recognizing the phase of the visualized objects in the quantity and quality as their nearest and furthest from the viewer and the difference in their shapes and the mediation between the viewer and the objects [El-Razieq,1991]p.119. The benefit of this science is in knowing how to see things and knowing the visual errors and their causes. This science helped the Mamluk architect in the perception or the imagining of the phase or the image of building during the design process, which is beneficial in order to recognize the third dimension of space.

3- Science of Areas.

This science deals with the study of a shape's area and a solid's volume. This science helps in recognizing the amounts, values and measurements of lines, surfaces and objects and determining the equivalent square or cubic line [Tash.Kubrĩ.Zadah,1985]p.353. The benefit of this knowledge is that one knows how to divide the land and assess housing.

4- Science of Weights.

This science deals with the process of setting the stones' weight in the construction, and determining its amounts and the machines which are used for weighing things. Therefore, this science helps in construction.

5- Science of Surfacing the Sphere

This science deals with the process of decomposition of the sphere into circles, and decomposes the circle into lines, Hajjĩ Khalĩfah defined it as follows:

"A science by which one can learn how to transfer the sphere to the surface with the maintenance of lines and circles drawn on the sphere, and how to transfer these circles to the line It seems that this science is very difficult to work by hand, but it is often handled by people, because there is no difficulty in this science to people who are experiencing and practicing the science of geometry." [Hajjĩ-Khalĩfah,1941]p.403. The sophistication in this science explains the perfection of the carved decoration on the roofs of the various domes in the Mamluk era.

2.5. Form and Space in Mamluk Religious Architecture

An initial reading of Mamluk architecture reveals form qualities governed by urban, social, and political factors, and, as a result, Mamluk monuments cannot simply be read as containers of spaces or objects in space, but rather as complex mediators between interior architectural spaces and exterior urban spaces. Individually, Mamluk monuments were more responsive to their context than initiators or dictators of new ones. It was from their collective power that a new concept of space emerged. Because of the way Mamluk architecture developed over time, it becomes clear that the concept of space expressed in it is not manifested in isolated buildings but in urban infills or complexes set in the midst of existing structures and built for public use [Al-Harithy,2001]p.73.

We will deal with form and space in Mamluk religious architecture by analysing its stylistic character and presenting its formal methodology, while focusing on three parts: demonstrating the primary geometric elements of space forming in Mamluk architecture, spatial geometric arrangements in organization of form and space and finally the methodology of symmetry (as one of the important geometric operations which the Mamluk architect depended on it in his composition) in the form composition, in order to understand how geometry controls and affects space composition in design process, and to attempt to understand the space-form languages which characterise the Mamluk religious architecture.

2.5.1. Primary Geometric Elements of Space Forming in Mamluk Architecture

"…, no part without whole; no reflection without source. In the field of geometry: no dimension without all dimensions. This elementary low of all phenomena can be symbolized geometrically in the way that space, seen as extension, is created by unfolding through the dimensions and can be 'folded up' again through the understanding of it nature. For instance, we take a point which, having emerged, proceeds to describe a line; the line moves laterally or in a curve to describe a plane; the plane rotates or moves in a further direction to describe (or create) the solid dimension (the third dimension)…" [Critchlow,1999]p.7. Following this idea, this section focuses on the point, line, plane and volume as the main and primary geometric elements of the space forming in the Mamluk religious architecture.

2.5.1.1. Point in Space Forming

The Mamluk architect depended on the point as a primary element of the geometric form generation process, which helped him reach the unity of space. This was achieved by the conformity of the orientation of the whole composition to the centre. This centre generated an ordering force onto the whole composition of the building. This point is vital to understand the importance of the centre as the point of beginning and end in the conception of Muslim medieval religious building [Gabr,1992]p.453. This centre in religious Mamluk architecture is the centre of the courtyard, which is the most important point in the form and the starting point of the whole building form design process. Besides that the Mamluk architect always used the point as a particular component of making the form in the facade design, particularly in the mausoleum facade design as well. Geometrically, this explains the power of the centre point in the form composition in Mamluk religious building, and how it guides and drives the architect's thinking during the whole design process.

Figure 2-34: The courtyard's centre point as a dominant element in all design of multi functional buildings in Mamluk Cairo

2.5.1.2. Line in Space Forming

There many architectural elements in Mamluk religious buildings, which used the line as a main primary element on its form and composition. For example, the minaret geometric form revolves around a line. The Mamluk architect used this line form as the connection feature between the different buildings on the same street. So in Mamluk Cairo, the many minarets along the same street integrated among themselves and with each other and draw a continuous and homogeneous geometric visual picture, as shown in Fig. (2-35e).

Geometrically, the direction of the line is a very important aspect because lines emphasize the direction in which they are going by leading the eye to create focus. The Mamluk architect used rows of bricks – as lines – in a contrasting colour to make the building look wider or narrower.

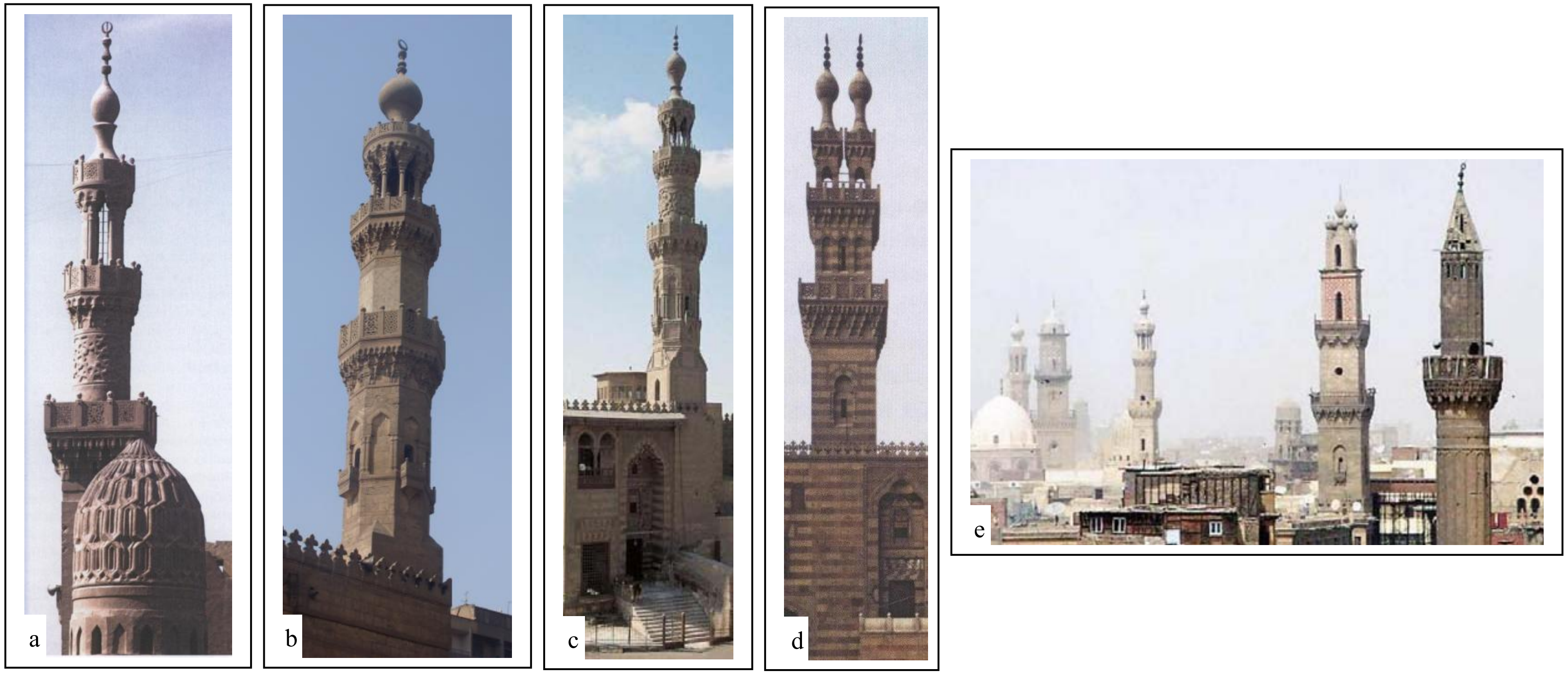

Figure 2-35: The minaret as a line in space forming
a- Mosque of Taghribirdi, b- Mosque of Qadi Zayn al-Din Yahya, c- Complex of Qaitbay,
d- Mosque of Amir Qanibay Qara, e- Panorama for al-Mu'izz Street minarets

2.5.1.3. Plan (Surface) in Space Forming

In the space geometric forming process the Mamluk architect dealt with the faces of the building facades, inside or outside, as a plan element. The analysis of madrasa building facades shows that the Mamluk architect dealt with every plan in the same facade individually and gave each its own personal architectural features.

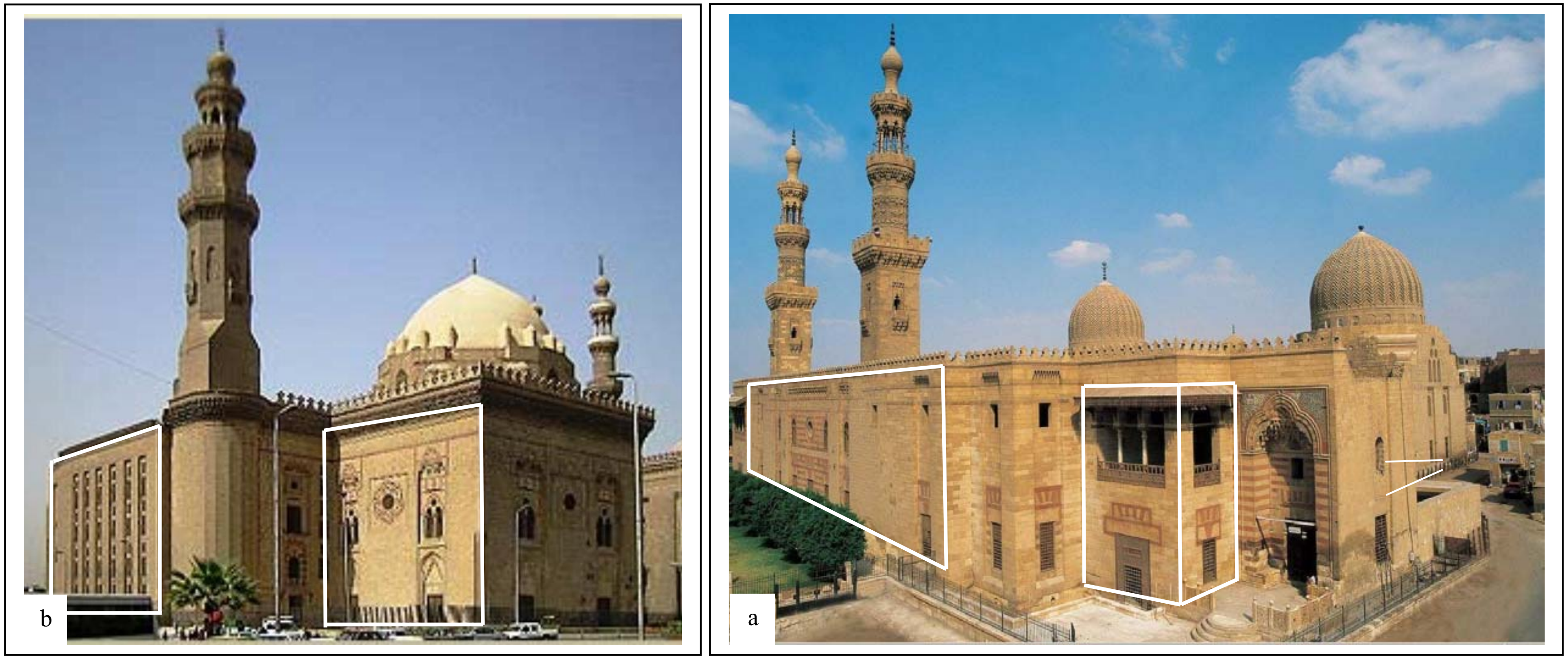

Figure 2-36: Using plan in space forming : The same facade contain different plans with individuals architectural treatment.
a- Madrasa of Sultan Hassan, b- Khanqah and Madrasa of Sultan Farag ibn Barquq in the Mamluk cemetery.

2.5.1.4. Volume in Space Forming

The Mamluk architect did not deal with the space only from the two-dimensional aspect, but also with the space as a volumetric object in a high degree of imagination to use and distribute it in the correct position for it to be suitable for the different functions inside the building besides the urban function of the form. The space of the iwan designed as a volume occupying all the height of the building and the same idea was applied to the entrance space, but the space of the other functions inside the building took another volume scale, as such as the space of the student's cells, the library space, the ablution space and the sabil-kuttab space. Therefore, it has to be said that the spacial organization and distribution inside the building was influenced by a volumetric view of the Mamluk architect. Fig. (2-37) shows how the Mamluk architect played with the volumes in the space design and how he could use different kinds of geometric volumes of spaces in the building composition.

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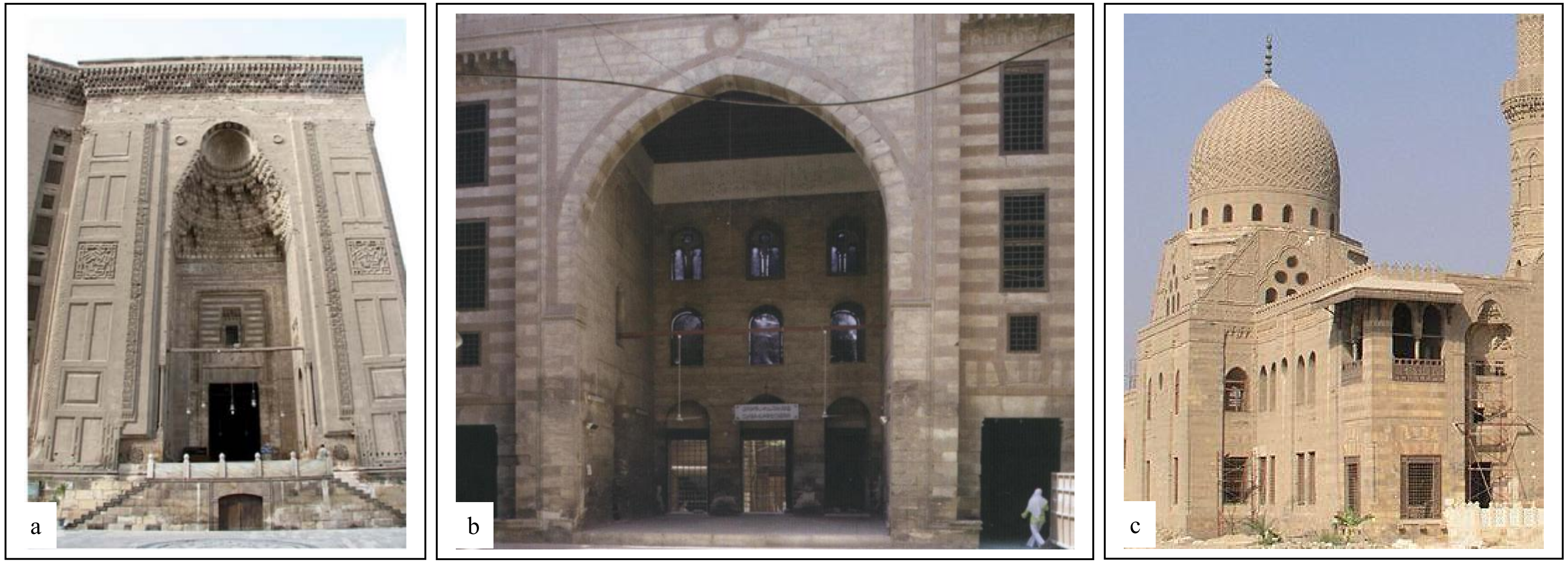


Figure 2-37: Playing with the volumes in the process of space forming in Mamluk architecture
a- The entrance in Madrasa of Sultan Hassan, b- The qibla iwan in Madrasa of Uljay al-Usufi, c- The mausoleum and Sabil kuttab in complex of Qaytbay

The following figure of complex of Sultan Qaytbay explains how the Mamluk architect used primary geometric elements of space forming as a very successful method in the geometric composition of the building. He used the end points of the facade as a point, the minaret as a line, the facades faces as a plane and the dome above the mausoleum form as a volume.

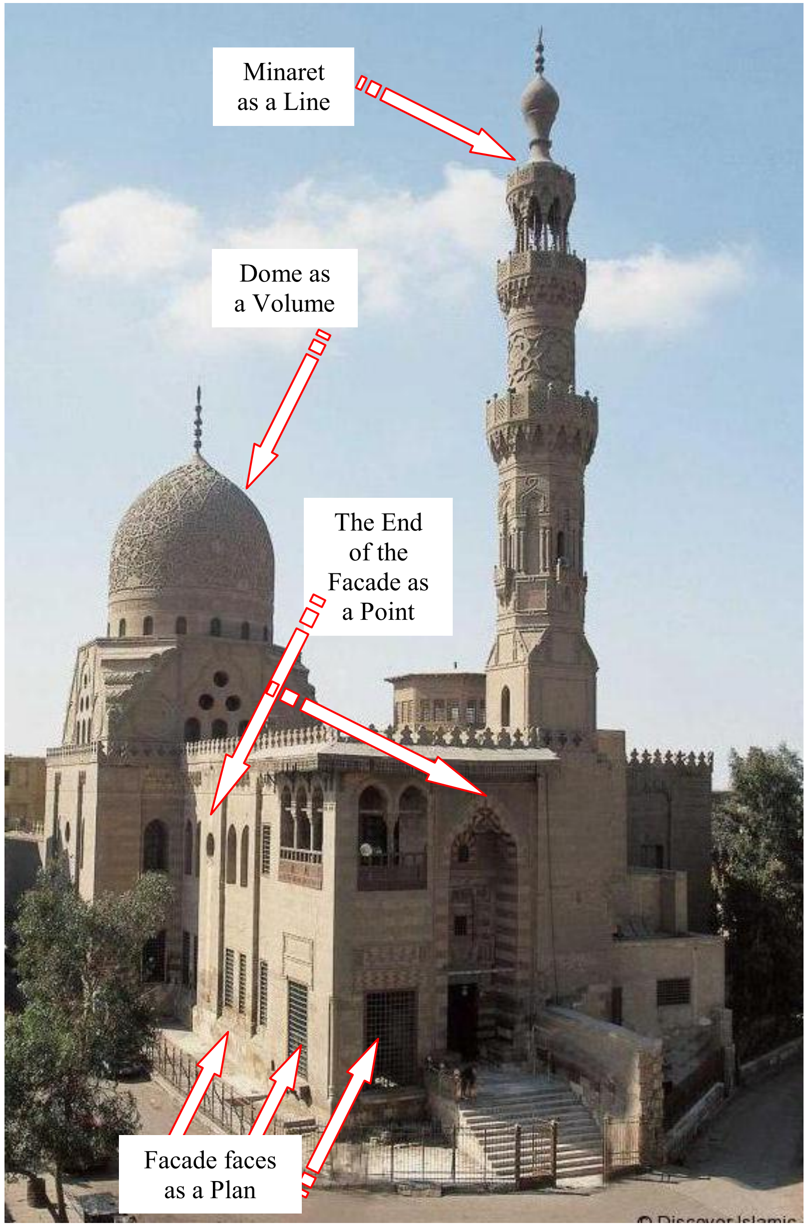


Figure 2-38: The primary geometric elements of space form in Madrasa of Sultan Qaytbay

2.5.2. Organization of Form & Space in Mamluk Religious Architecture

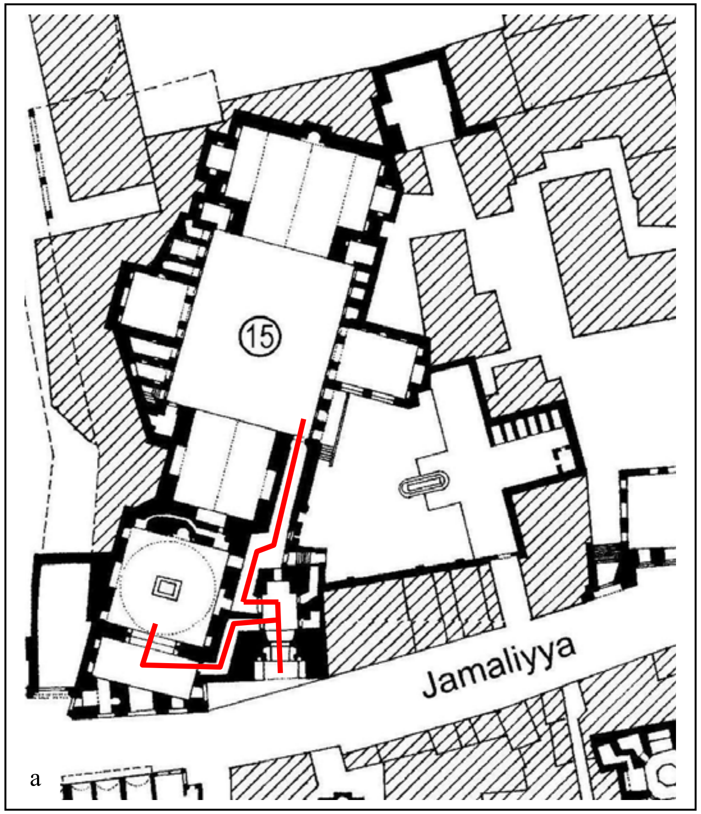
Architecture is a part of an art where formal principles are very important for creators and spectators. Form in architecture is extremely important. Understanding the forms, which have provided the basis for Mamluk architecture, in light of the laws and rules which control the generating process of space form, allow researchers to observe, through the analysis of religious buildings design, how small elements are inserted in a continuous and coherent whole. It could be said, in this regard, that the general form is not what counts the most, but rather, what is really important is the way in which parts are held together.

The question is: How can geometric forms be described and classified in Mamluk religious architecture? The study and research in Mamluk religious architecture geometric form composition allows us to present four main laws controls the generating process of space form. These four laws are[20]:

1. The Law of Unity: unites all entities;
2. The Law of Opposites: each entity has a polarity;
3. The Law of Development: entity develops through transformations;
4. The Law of Connections: uses parts of the form to connect other parts.

The law of unity is the law which unites all form entities in order to obtain the unity in form. That can be done, for example, by using the courtyard in all parts of the form to serve all different building functions. The law of opposites means that each entity in the form has its polarity, and that can be, for example, the contrast between the minaret as a very tall line element and the dome as a sphere short elements. The law of development is the law which governs the process of development of every entity in the form through transformation. That can be done, for example, by using the same composition of one recess of the facade window while the object continues to cover the entire facade. The law of connections is the law which insures homogeneity in the form especially when parts of the form are used as connection elements between the form components. That can be done, for example, by using the kuttab in the corner of the buildings as a connecting element between the building’s two facades, the writing decoration panel to connect all the building facades, and the corridors (majaz) to connect the entrance and the sahn,

[20] More investigation and more research in the field of form/space in Mamluk religious architecture can present many other laws of composition, but we will concentrate on these four, and presenting them briefly. Relationship between the form and space in Mamluk architecture can be discussed in details in sophisticated and specialized future researches.



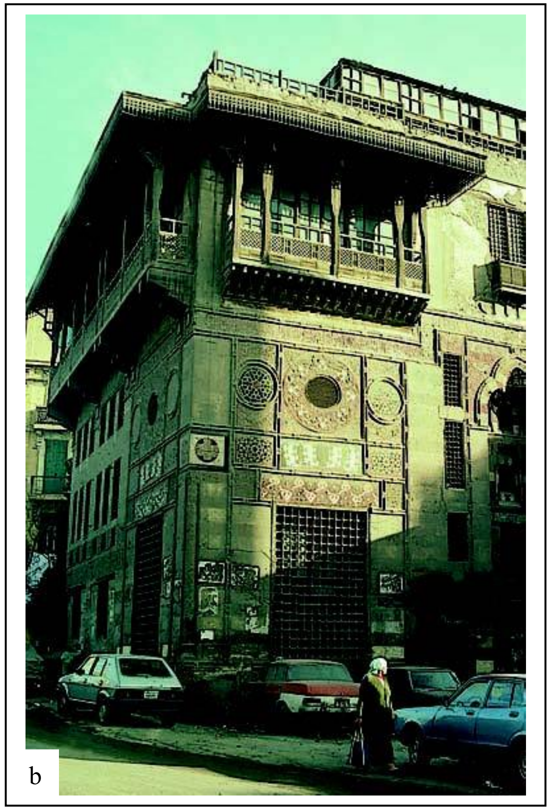


Figure 2-39: Connections in form in Mamluk religious architecture
a- The Khanqah of Baybars al-Jashankir used the corridor as a connection element (Majaz) between the entrance and the sahn and all building spaces. b- The Sabil-Kuttab of Qaytbay used the same treatment in the perpendicular facades,

2.5.3. The Methodology of Symmetry in Form Composition in Mamluk Religious Architecture

Geometric transformations in form composition in Mamluk religious architecture take place through many geometric operations. Symmetry is one of the most important geometric operations which the Mamluk architect used in the process of form transformation. The use of symmetry in Mamluk religious buildings architectural designs may sometimes be apparent immediately just by looking at designs, although the final design is seemingly asymmetrical. The symmetry manifestation and the methodology of symmetry in Mamluk religious architecture are presented.

2.5.3.1. Manifestations of Symmetry in Mamluk Religious Architecture

If one takes a look at the manifestation of symmetry in Mamluk religious architecture, four types of symmetry geometric transformation will be found in the facade design, in the plan design and also in a clear vision in space composition. In all cases a certain geometric transformation operation is performed; during these transformations one (or more) geometric properties (orientation, position, scale) of the geometric object remain unaltered. The four types of symmetry transformation are demonstrated as follows:

1- Reflection

If there is a shape in the plane and a straight line, all points of this shape can be reflected through the straight line and a mirror shape of the original is obtained. The two shapes are symmetrical because the mirror-shape preserves all properties of the original, as shown in Fig. (2-40 a).

The symmetry by reflection takes three different forms according to the number of the reflection axis. The first is one simple axis. The second form is two parallel, or staggered axialities. The third is a multiple axiality as shown in the following figure.

Figure 2-40: The reflection symmetry manifestation in Mamluk religious buildings
a- The reflection symmetry manifestation, b- Reflection symmetry in Madrasa of Sultan Barsbay,
c- The reflection symmetry in the entrances and Iwans compositions in Complex of Amir Azbak al-Yusufi.

2- Rotation

If there is a shape in the plane and a straight line perpendicular to the plane, as the axis of rotation, and all points of the shape are rotated from (equal) an angle of any a choice around the axis, the rotated shape preserves its properties. Only its placement in the plane and orientation changes, as shown in Figure (2-41).

Figure 2-41: The rotation symmetry manifestation in Mamluk religious buildings.
a- The rotation symmetry manifestation, b and c : Complex of Emir Sarghitmish plan and isometric show the rotation symmetry between the mausoleum space form and the qibla iwan

3- Translation

Take an object, a direction, and a distance. Move the object in the fixed direction by the given distance, repeating this transformation any number of times, in principle ad infinitum. It never gets back to the original, but a series of copies of the original object are generated. The object preserves all its properties, except for its location in the plane (in space), as shown in Fig. (2-42).

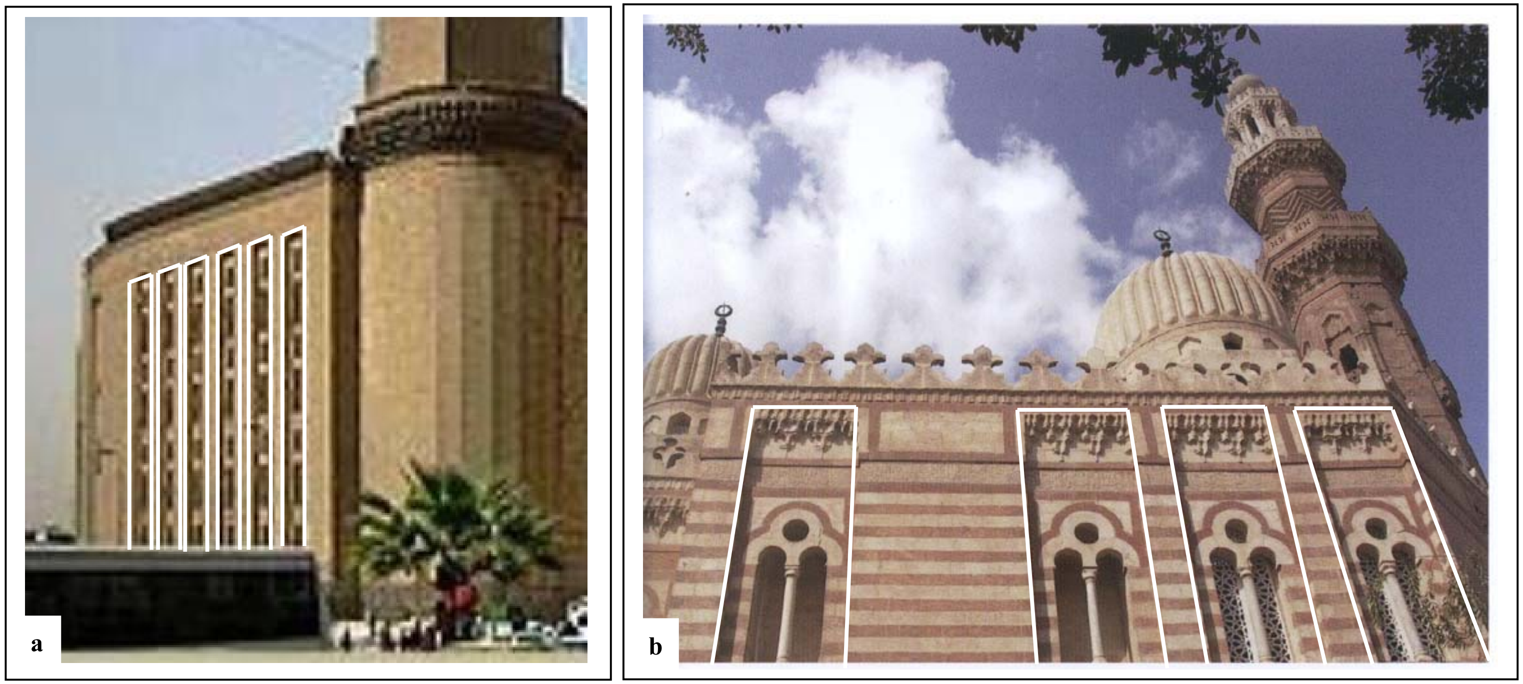


Figure 2-42: The translation symmetry manifestation in the facades of Mamluk religious buildings.
a- The translation symmetry in Madrasa of Sultan Hassan, b- The translation symmetry in the facade in Madrasa of Um al-Sultan Shaban

4- Similitude

Similitude is a symmetry transformation whereby the distances between the corresponding points of two objects change, but the ratios between the lengths and the angles are preserved; thus the shape of the object remains similar to the original [Darvas,2003], as shown in Fig. (2-43).

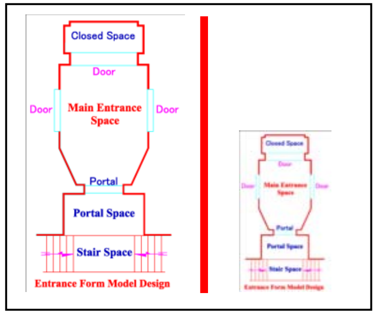


Figure 2-43: The similitude symmetry manifestation in the entrance form

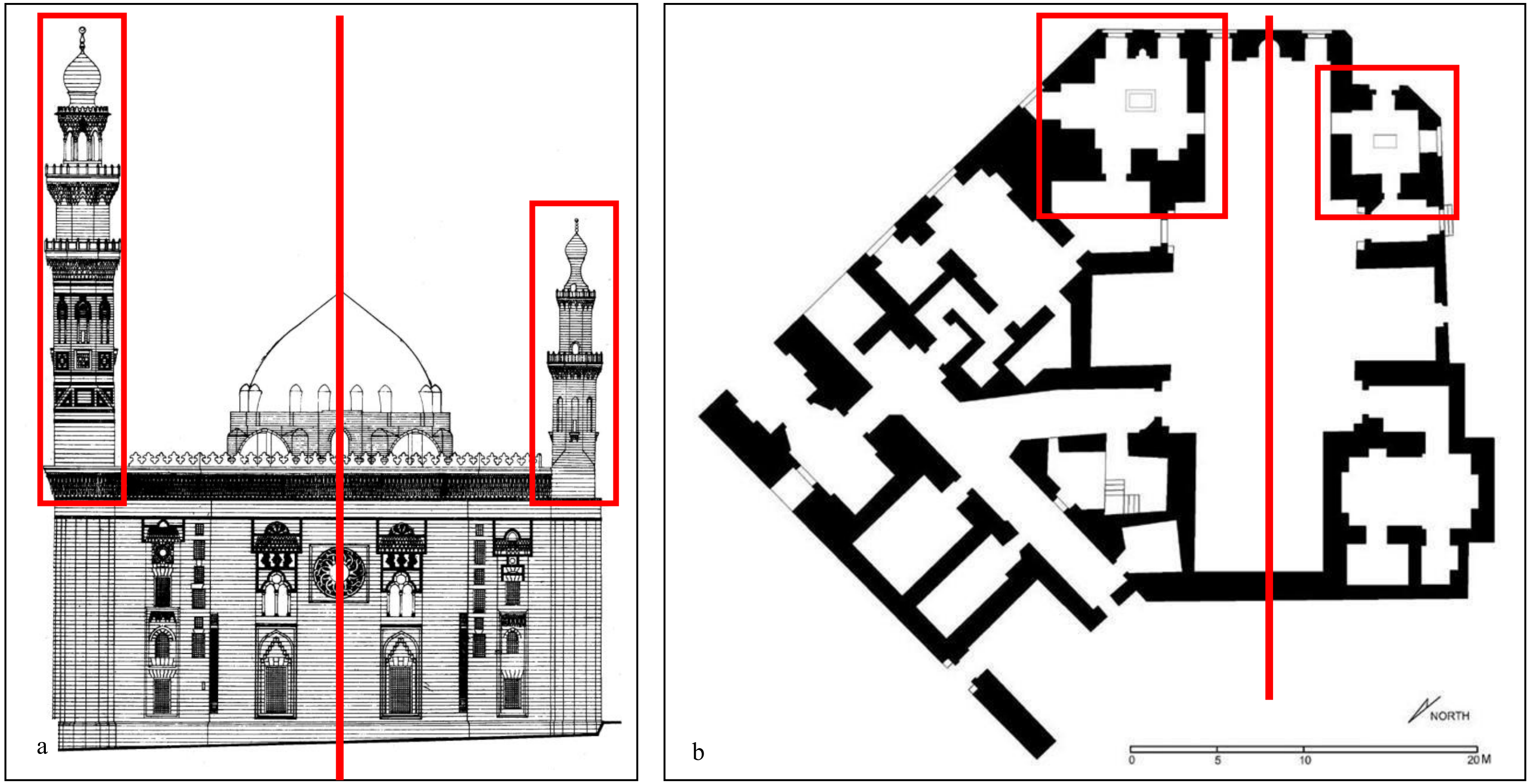


Figure 2-44: The similitude symmetry in Mamluk religious buildings
a- the similitude symmetry in the two minarets of Madrasa of Sultan Hassan (at the recent appearance because they were totally symmetric when they were built),
b- The plan of Madrasa of Umm al-Sultan Sha'ban shows the similitude symmetry in the two mausoleum space forms and their masonry dome.

2.5.3.2. The Mamluk Methodology of Symmetry

The methodology of using symmetry in geometric form composition in Mamluk architecture depended on the symmetry operations, which were concerned with spatial displacements or motions that take a geometric shape and move it in such a way that all the elements of the shape overlay one another precisely, so that, despite the displacement, the shape appears not to have moved from its original position. This explains how all the various types of geometric symmetry transformation which the

Mamluk architect had used are superimposed onto individual designs, and how symmetry was employed strategically in the design process.

The Mamluk architect utilized geometric symmetry operations, in particular reflection and rotation, to generate plan prototypes as well as their variations. Whereas in most cases the whole design is seemingly asymmetrical, despite an almost obsessive concern for symmetry in its individual parts, the analysis demonstrates how various symmetry operations are involved in each of the parts of the design, revealing the underlying structure of its geometric order. Thus, the Mamluk architect's use of symmetry principles in the design becomes more evident. From the previous presentation of the manifestation of symmetry in Mamluk religious buildings it was found that the Mamluk architect had used the geometric symmetry to play the role of the secret agent which controls his facade design besides using it in the geometric spatial arrangements of the building spaces.

A study of the fundamental principles of geometric forms in the Mamluk architecture is an essential prerequisite for the wider understanding of complex designs as well as the creation of new architectural forms. This understanding of the fundamental principles would aid the generation of new creative work through modification, transformation and development. Symmetry demonstrates the geometric relationship between the parts and the whole. The Mamluk architect connected almost every part of the complex composition with geometric relationships; understanding these mutual relations is very important in the process of developing or modifying the whole composition. From that, symmetry can be considered as an effective method for reading the geometric order of complex designs as well as for composing new designs in architecture.

The Mamluk architect's formal methodology clearly elucidates different hierarchical levels of the use of symmetry in religious building architectural designs. His methodology of geometric symmetry explains his sophisticated understanding of the formal and geometric aspects of his architectural work, and clarifies the design ideas alongside many of the fundamental principles of architectural composition. The architect, who wishes to deal with the geometry phenomena in architectural space, has to have not only innate talent, but also a method, such as geometric symmetry principles, to help him visualize the space forms in his mind and consequently improve "his mental image" of the space geometry.

2.6. The Urban Context and the Mamluk Religious Architecture

The city of Cairo as an example of the cities of the Middle Ages, in the beginning formed the opening of 'Amr ibn al-'Aas to Egypt, where he built the city of "Fustat" in the year 21 AH / 642 AD. Then, the Abbasids built the city of "Al-'Askar" in the year 132 AH / 750 AD to the north-east of Fustat, and when Ahmed Ibn Tulun settled in Egypt and began to establish an independent state from the Abbasid caliphate, he founded the city of "Alqata'i'" in the year 256 AH / 870 AD. When Gawhar al-Siqilli invaded Egypt, he established the city of Al-Qahira "Cairo" in 358 AH / 969 AD. Thus Cairo became the fourth capital for the Muslims in Egypt in Fatimid era. Therefore, the city of the Mamluk was inherited from the Ayyubids including the historically important Fatimid walled city. Despite the remarkable growth of Cairo's suburbs and satellites, and Mamluk sultan's incitement of the amirs to build monuments and mansions in the new area, the most desirable location for a residence or a monument remained the densely populated area of the walled Fatimid city, particularly on the qasaba[21], the main street, from Bab Zuwayla to Bab al-Futuh. This is a brief description of the urban growth of Cairo. It is shown how the inherited urban context of Cairo was architecturally an important factor. This section demonstrates how the Mamluk Cairo urban context affected the Mamluk religious monuments design, and how the Mamluk architect could solve the complex relationships between the different architectural elements inside his complex religious buildings in regard to the urban context.

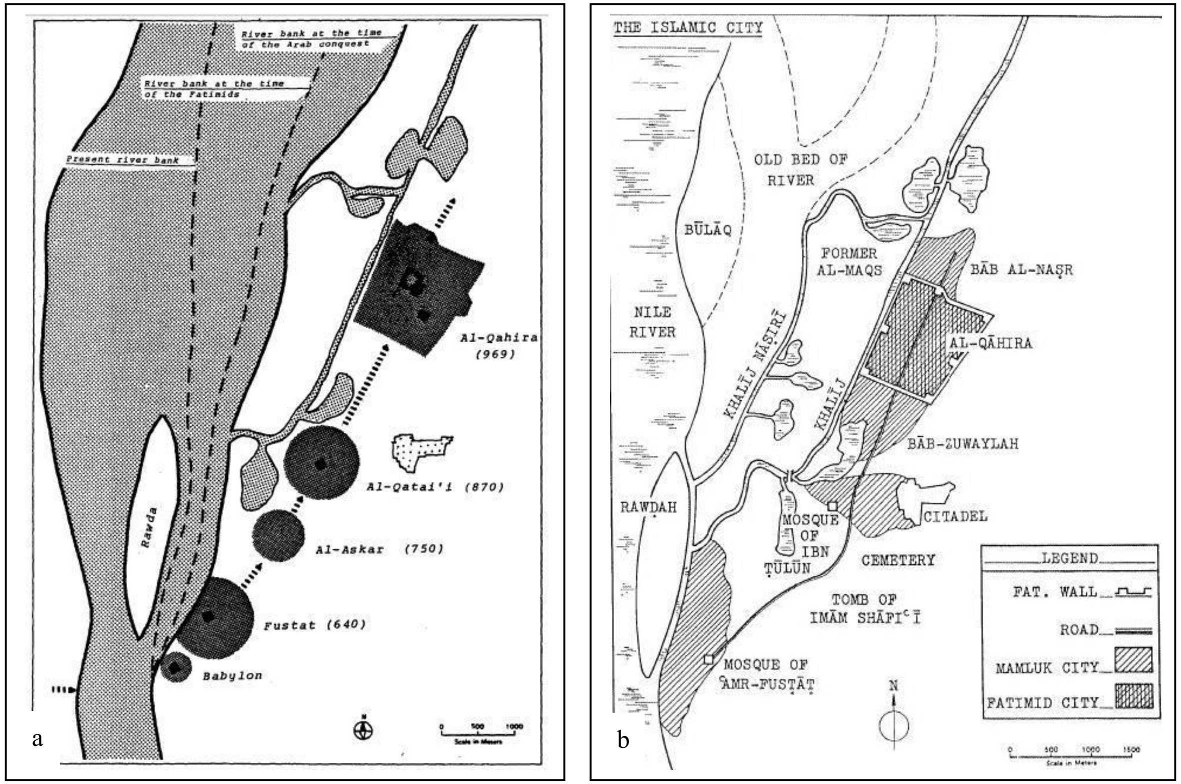


Figure 2-45: Historic Cairo map.
a- The site of Cairo and the early Muslim settlement,
b- Map of Cairo in the early Mamluk period

[21] **Al-Mui‘zz Street** (Shari‘a al-Mui‘zz li-Deen Illah, al-Shari‘a al-‘Azam, Shari‘a al-Qahira, Shari‘a al-Qasaba) in Islamic Cairo, Egypt is one of the oldest streets in Cairo. The street (Shari‘a in Arabic) is named for Al-Muʿizz li-Deen Illah, the fourth caliph of the Fatimid dynasty. It stretches from Bab Al-Futuh in the north to Bab Zuweila in the south.

2.6.1. The Effect of the Urban Context on Mamluk Religious Building Design

Mamluk architects were trying to avoid obscure space in buildings and they were aware of the need to give geometric expression inherent in their design besides using different geometric volumes of spaces, and that makes buildings both practically and functionally successful. There were many effects of the urban context on the Mamluk religious building design. These effects led to the emergence of many elements (architecture or urban elements) and treatments (architecture or urban treatments), which added to the building design, leaving the effects to appear in the final form of the building. Some of them are mentioned as follows:

2.6.1.1. The Emergence of the Complex Solution in Buildings Design

The sites on which monuments in the Mamluk era were constructed were often those of residences which had been purchased and torn down, and could be almost any shape. That was a problem with which Mamluk architects were familiar, given a situation in which the streets preceded the monuments. Monuments in the old city had to meet three often differing needs - to be imposing, to face the street, and to face Makkah [Williams,1984]p.39. This led to the emergence of complex solutions in the religious buildings design. The first religious structure of the city to be built on a Makkah axis differing from the street-entrance axis was the Fatimid mosque of al-Aqmar, built in 519/1125. This problem was rather easily solved by making the facade thick on one side and thin on the other, inserting a series of diminishing chambers, and skewing the mosque courtyard to the southeast. It is no exaggeration to say that the Mamluk architects could build Makkah-oriented monuments almost anywhere, and that in no other Islamic city were so many adjustments of monument to site necessary: this is one of the distinctive features of Mamluk architecture.

The sultans were able to build monuments along the winding side streets of the old city, and did so throughout the Mamluk period; however, the available sites usually presented a problem. The streets were already laid out and could not be altered, and the facades of the monuments had to be aligned with them. A madrasa, khanqah, mosque, or mausoleum had to face Makkah, to the southeast of Cairo. Since the reason for building a monument in the first place was usually to shelter its founder's tomb, it had to appear prominently on the street side. Monuments were visible symbols and sources of power. Their individuality was expressed in the arrangement of the mausoleum dome, the minaret, and the portal, which were so disposed as to dominate the view and assert control of the public space of the street.

All of these different demands - solving the inside complex functions' relationship, solving the outside complex mutual urban' relationships, improving the geometric visual and spatial relationships between the building's architectural elements and facing the different conditions of the building site - lead to the emergence of complex design solutions. One of the distinctive complex solutions the Mamluk architect used was dividing the building into two parts so that the building straddled the street, with both parts facing each other and connected, as in 736 A.H./1336 A.D. Bashtak built a khanqah facing a Friday mosque, to which it was connected by a bridge across the street. The following figures show how the Mamluk architect could geometrically arrange his building parts across a street side.

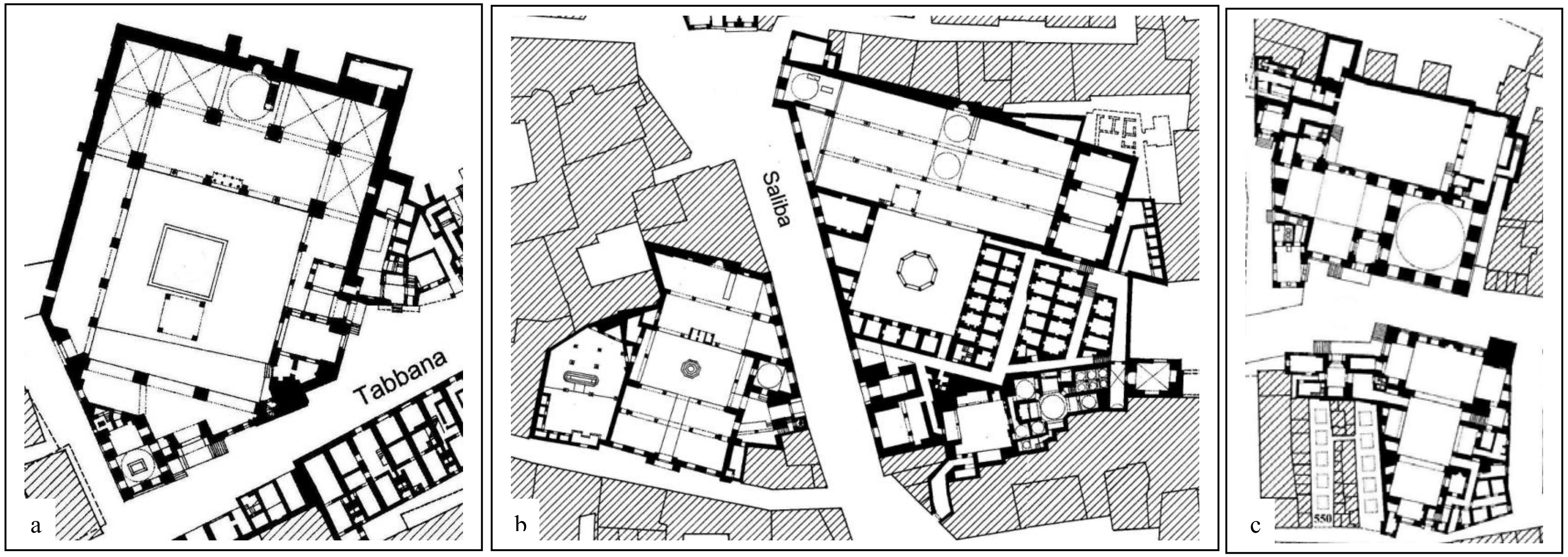


Figure 2-46: The architectural complex solution in Mamluk religious buildings
a- Mosque of Aqsunqur, b- Mosque and khanqah of Amir Shaykhu al-Umari, c- Complex of Sultan al-Ghuri

2.6.1.2. The Emergence of the Visual Continuity in the Urban Context

The visual continuity in religious Mamluk architecture can be seen in three positions. The first is the visual continuity in the same building. In this case, the visual continuity occurs in two facades facing two different streets. The second is the visual continuity between different buildings' facades straddling the same street. The third is the visual continuity between the interior architectural space and the exterior urban space.

In the Madrasa of Sultan Qalawun, the facade decoration panel joins all the building facades, and also the fenestration system treatment is the same all over the building's facades causing a visual continuity all over the building, even though the internal space functions are different; also the treatment of the windows and portals as well as a succession of recessed layers generated inward visual movements, as shown in Fig. (2-47b). The recess panels in the facade are popular features in Mamluk religious architecture. Various adaptations of these panels are found in the Madrasa of Sultan Qalawun and the Madrasa of Sultan Barquq causing a visual continuity through the street between the two buildings facades by using the same architectural treatments as shown in Fig. (2-47a).

The visual continuity between the interior architectural space and the exterior urban space emerges because of the growing interdependence between the interior and exterior space in Mamluk religious architecture. The Mamluk architect could solve and control the degree of fluidity between the two spaces by using the transitional space. This task gave rise to a new spatial sequence composed of entries, vestibules, corridors, and also the entrance. The Mamluks developed it by introducing the indirect entrance as a part of the transitional space and spatial unit with a role to play in the sequential transition between exterior and interior space. So, in general the role of this transitional space was better defined as a transition between the street and the building, the space through which the approach to the building was controlled, noise reduced, and privacy ensured.

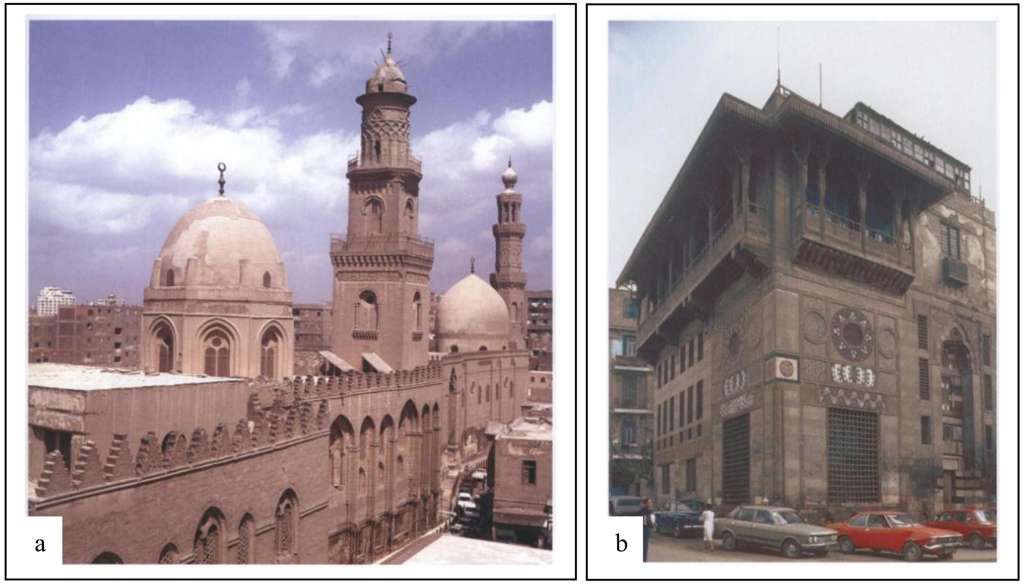


Figure 2-47: The visual continuity in Mamluk religious buildings design
a- Facades of Complex of Sultan Qalawun and Complex of Sultan Barquq show the visual continuity through the street,
b- Sabil-Kuttab of Sultan Qaytbay shows the visual continuity through the building facades by using the same architectural treatment.

2.6.1.3. The Emergence of Spatial Unifying Elements

The spatial unifying elements are the elements which provide the unity to the visual image of the viewer, from the same street or inside the building. Windows and doorways run the length of the street facades in the religious buildings in Mamluk architecture which provides the visual and physical access to all the buildings, always playing the role of spatial unifying elements in the urban design. Inside the building, the corridors play the role of the spatial unifying elements. The most obvious example can be seen in the design of Sultan Qalawun Madrasa. The symmetrical arrangement of the corridor, with the windows and doorways on the mausoleum side corresponding to those on the madrasa side, reinforced its role as a spatial unifying and spatial-organizing element and as an extension of the streetscape, as shown in the following figure.

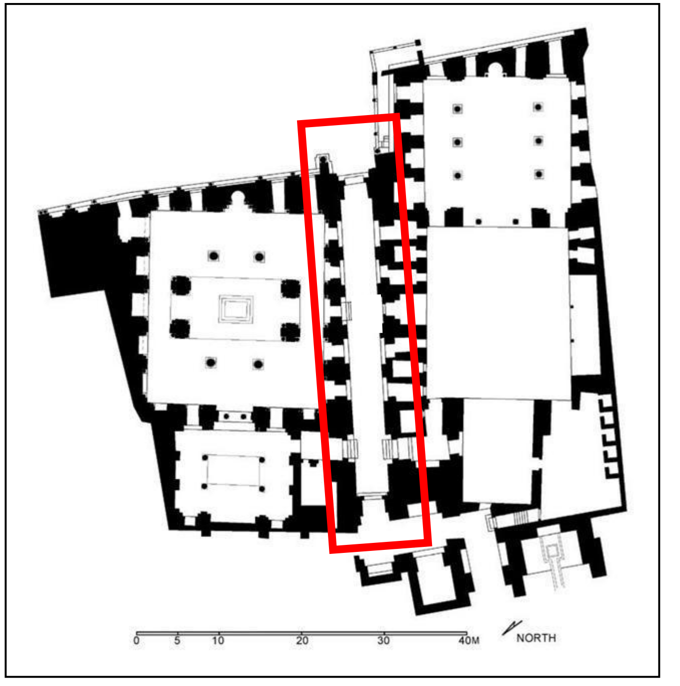


Figure 2-48: The great corridor is the spatial unifying element in Madrasa of Sultan Qalawun.

2.6.1.4. The Emergence of the Urban Pocket

The "urban pocket" is a spatial pause along major spines or paths. The purpose of such an expansion was to reorient the observer, to acknowledge an entry into a building, or to generate a place of social interaction [Al-Harithy,2001]p.84.

Formal efforts to define the open spaces, which were immediately outside the buildings and to make them urban pockets are found throughout Mamluk architecture. The Mamluk architect played with the placement of the significant architectural elements and the treatment of the facade in order to define both the form and the character of this open space or pocket, to be a space without boundaries of its own. Through contraction and expansion of the building mass he could make a clear distinction between the street and the urban pocket, but at the same time not obstructing the flow along the path. Four examples of religious buildings are presented to demonstrate how the Mamluk architect created the urban pocket in his design.

Case 1: Madrasa of Sultan Qalawun (urban pocket formed between two different buildings across the street)

The layout of the building reflected a developed sense of urban perspective, as shown in Fig. (2-49a). The location of the minaret was in the northern corner beside the mausoleum and the slight angle between the portal and the rest of the facade; furthermore, the projection of the madrasa onto the street opposite the Madrasa of al-Salih Najm al-Din led to the formation of an urban pocket space.

Case 2: Madrasa of Sultan al-Ghuri (urban pocket formed between the building two parts across the street)

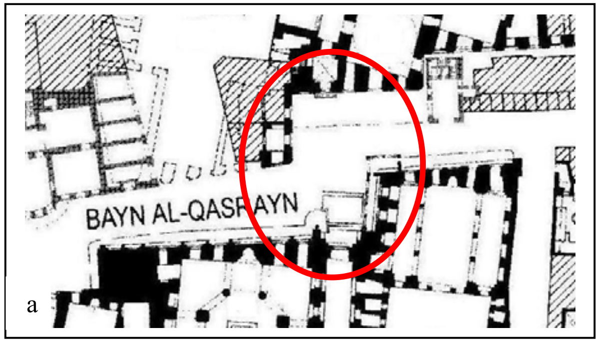
The funerary complex has a remarkable layout as a double architectural composition, with two blocks straddling the main street in the heart of medieval Cairo. The western block consists of a mosque with its minaret; the eastern one is a funerary complex. The facades of the two buildings display two projections, that of the minaret on the south-western corner and that of the sabil-kuttab on the opposite one forming the space between them as an urban pocket, as shown in Fig. (2-49d).

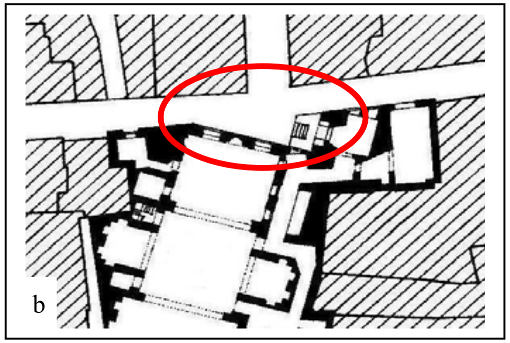
Case 3: Mosque of alTunbugha al-Maridani (urban pocket formed by the building composition)

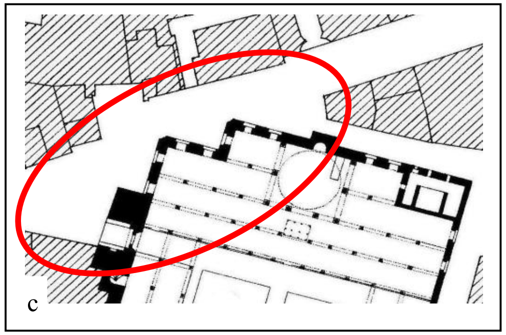
The mosque is located on al-Tabbanah Street at a bend in the road. It takes complete command of its urban setting. The configuration of the mosque's edge takes full advantage of the streetscape: the jagged corner of the building and the volumetric position of the portal allow the street to expand to form an urban pocket in front of the entrance, as shown in Fig. (2-49b).

Case 4: Madrasa of Jaqmaq (urban pocket formed by the building composition)

The building is squeezed in the street of Darb Sa'ada; its facade forming an angle. The portal and the sabil-kuttab are on one side and the minaret on the other, forming an urban pocket between them, as shown in Fig. (2-49c).







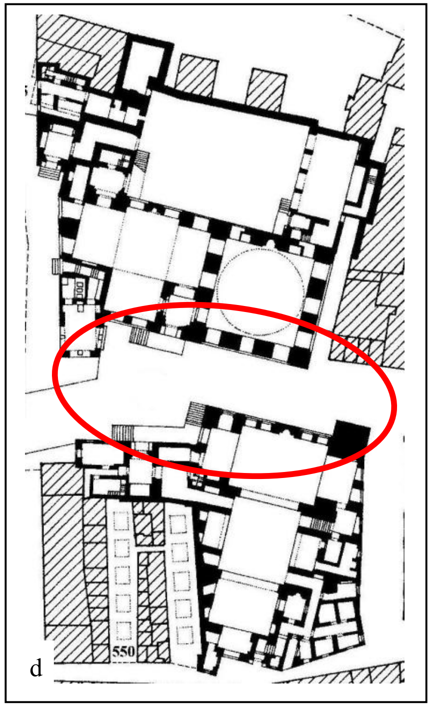


Figure 2-49: The urban pocket in Mamluk architecture
a- Madrasa of Sultan Qalawun urban pocket,
b- Mosque of al-Maridani urban pocket,
c- Madrasa of Jaqmaq urban pocket,
d- Madrasa of Sultan al-Ghuri urban pocket.

2.6.1.5. The Emergence of the Urban Walls

The urban wall is the building's outer wall, which separates the building's interior design and the outer site urban design. It is a wall which plays the role of the secret agent accommodating the strong interior architecture design rules and the strange building outside site conditions. It is a tool the designer uses in order to make a mediating relationship between the building design and site circumstances. These urban walls emerge when the building site is an awkward shape or, for some other reasons, such as turning toward Makkah to pray, the main space of the buildings has to be at an angle to the street. The following figures show the building site and the architectural treatments which the Mamluk architects had made on the building outer urban wall.

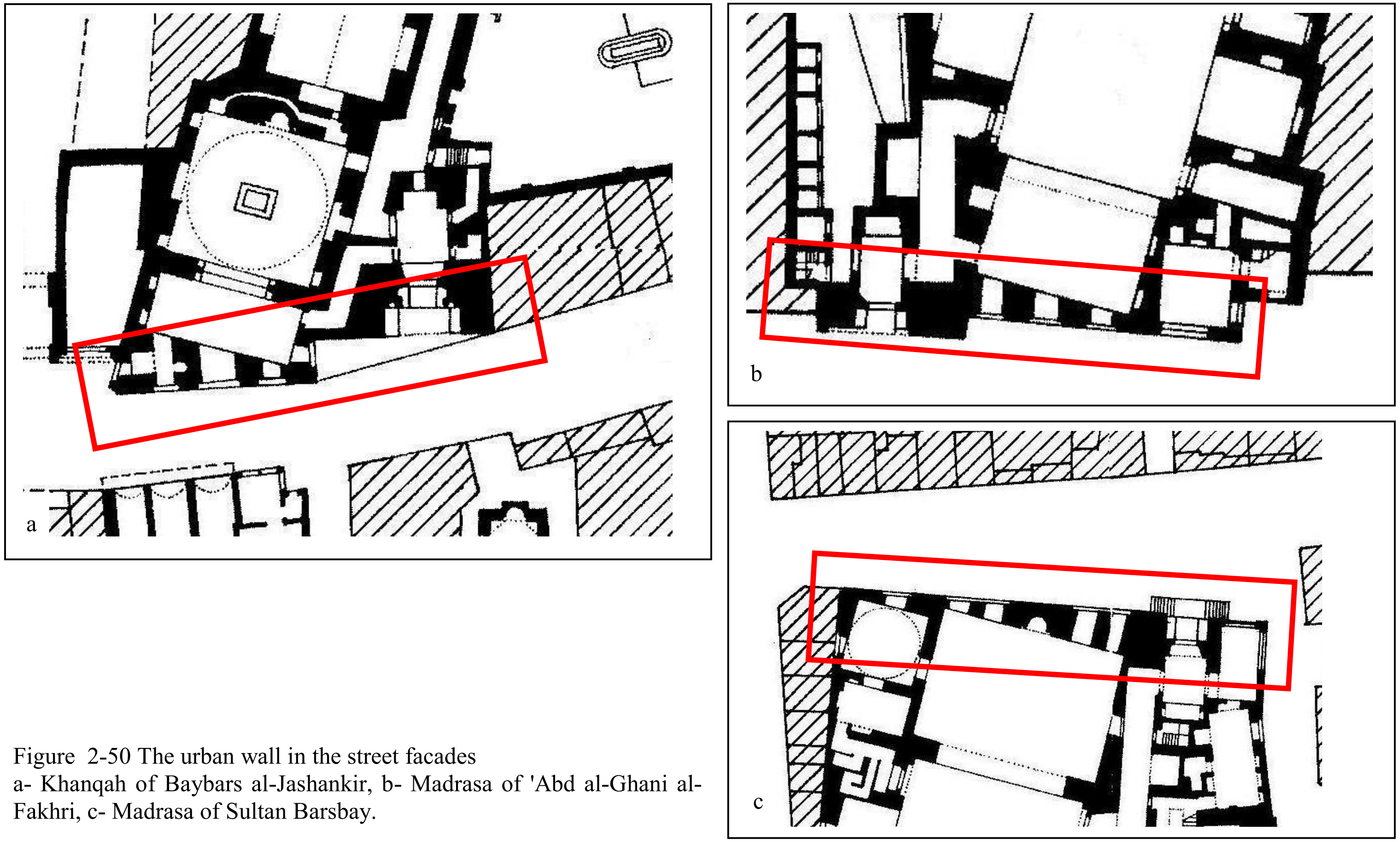


Figure 2-50 The urban wall in the street facades
a- Khanqah of Baybars al-Jashankir, b- Madrasa of 'Abd al-Ghani al-Fakhri, c- Madrasa of Sultan Barsbay.

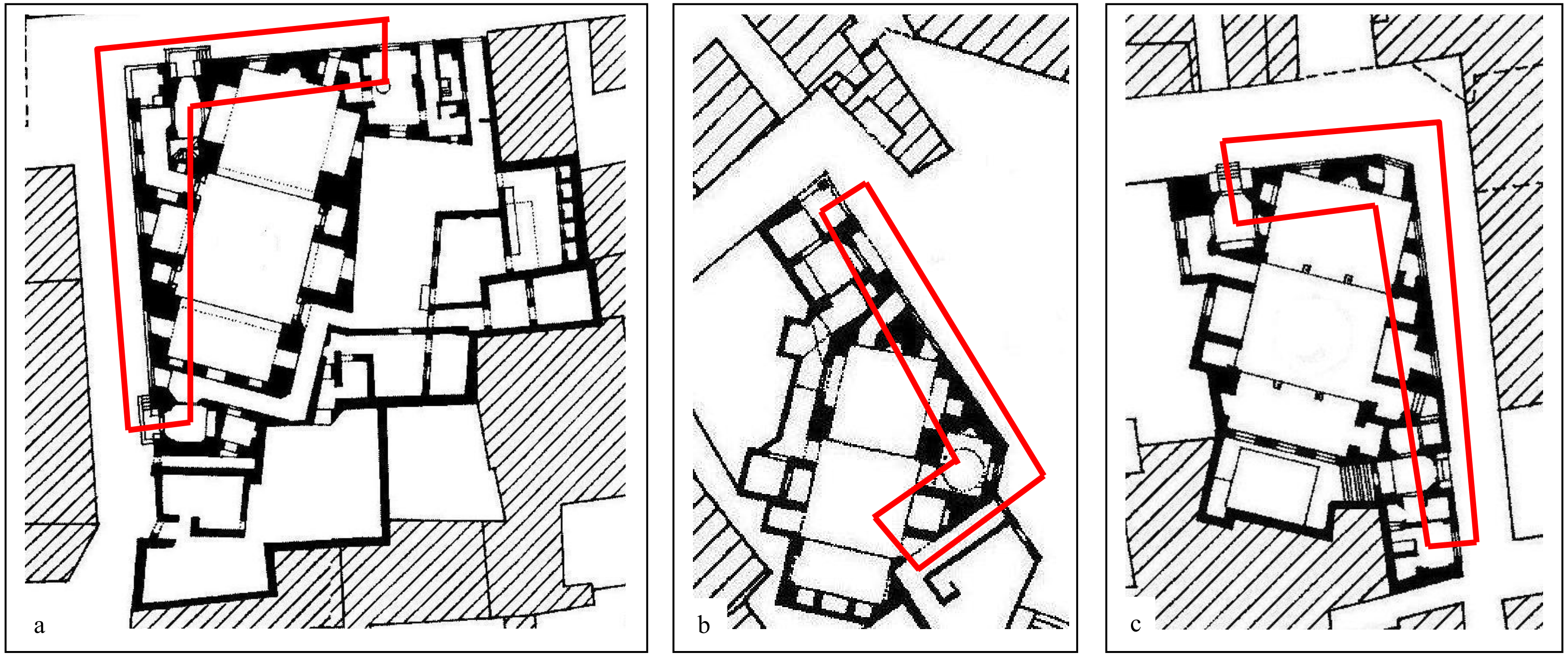


Figure 2-51 The urban wall in case of corner site buildings.
a- Mosque of Qadi 'Abd al-Bassit, b- Mosque of Jawhar al-Lala, c- Mosque of Qadi Abu Bakr Ibn Muzhir.

The urban wall is the outer wall in the building and its role is to absorb all the building form deformations, which results from the effect of the site on the building form. That absorption generates and produces regular spaces inside the building, suitable for the internal architectural different functions. The architect put on it many treatments to produce that mediating relationship between the building design and the site conditions. Treatments include changing the wall thickness and making many solid parts in the wall in order to reduce the negative effect of the deformation on the enclosed designed space.

2.6.1.6. The Emergence of the Urban Facade

The urban facade was designed to increase the level of communication not only between the building and its users but also between the building and its physical environment. The building came to address the street, the neighbouring buildings, and the image of the city as a whole. Though respecting and responding to most challenging urban conditions, these facades also retained their aesthetic and symbolic value. The urban facade was more than just the front of the building; it was an architectural element closely associated with public open spaces, such as streets and squares. That does not merely represent the physical character of the building but is also expressive and symbolic. The urban facade is more than a device that separates inside from outside and public from private; it imparts meaning and initiates a dialogue with its immediate surroundings and with the viewer [Al-Harithy,2001]p.87. Mamluk facades ceased to be ends in themselves and began to be given a role in urban life by relating to their surroundings.

The essential components of the urban facades are entry, orientation, and embellishment, besides the balance between the sense of verticality and horizontality. The Mamluk architect used vertical elements such as the portal, the minaret and the dome to introduce the sense of verticality and balanced that with the use of the horizontal elements such as the horizontal Ablaq and inscription bands.

Figure 2-52: The balance between the horizontality and verticality in Madrasa of Sultan Barsbay.

2.6.1.7. The Emergence of the Axial Articulation Form

There is a main axis in the Mamluk religious buildings. All the building spaces and forms are articulated around it, generating the axial articulation form. This articulation axis in the plan is always the qibla direction, which indicates the prayer orientation to Makkah. All the building spaces and forms are articulated around that axis, as shown in the Fig. (2-53a). However, the reflection of the qibla direction axis can be found in the design of the mausoleum facade or the madrasa facade. This articulation axis is the hidden and the secret factor which connects and gathers the building plan design and the building facade design, through the reflection of the plan design on the facade fenestration system. Beside this articulation axis, another articulation axe in the facade is found. This is the minaret axis which articulates around it all the forms and decoration elements to generate the axial articulation form, as shown in the Fig. (2-53b).

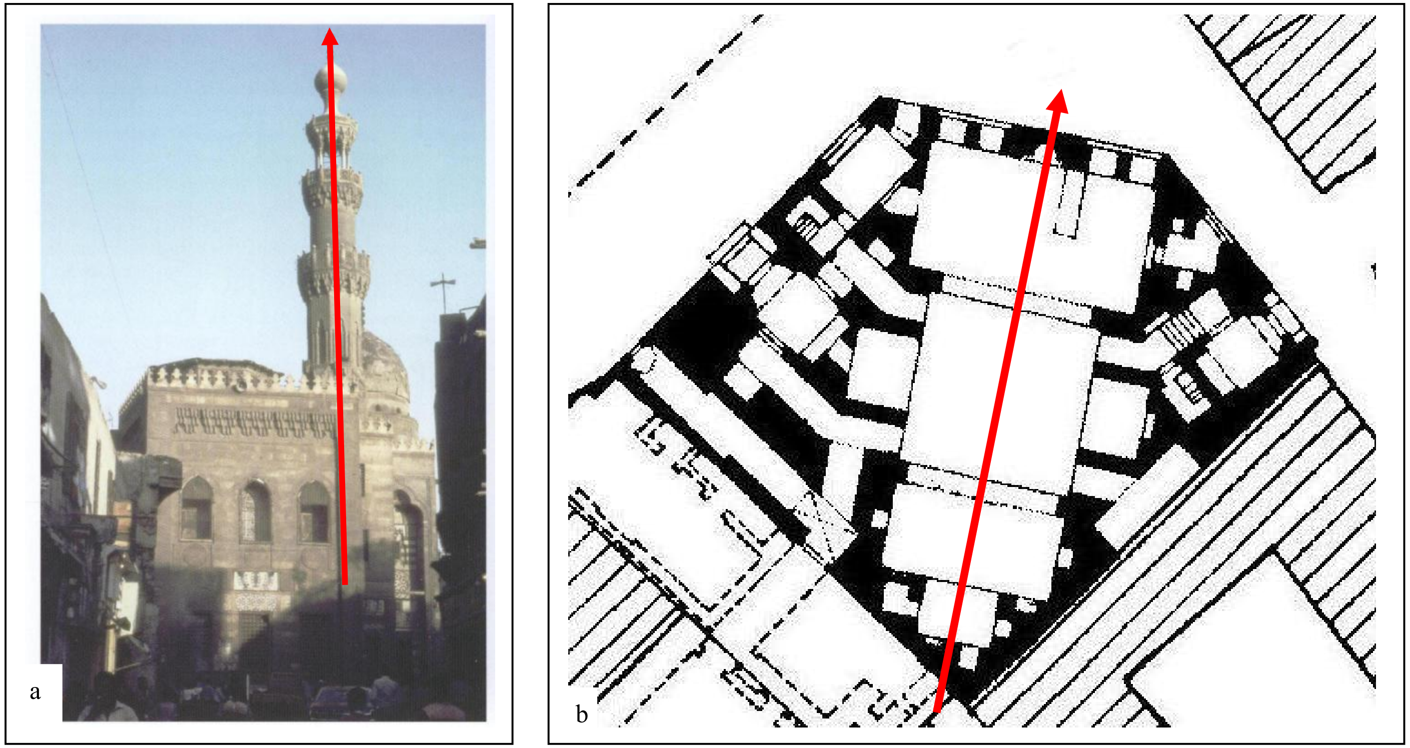


Figure 2-53 The axial articulation form in Mamluk religious buildings.
a- The Minaret in Mosque of Qijmas al-Ishaqi, b- The plan of Mosque of Amir Azbak al-Yusufi.

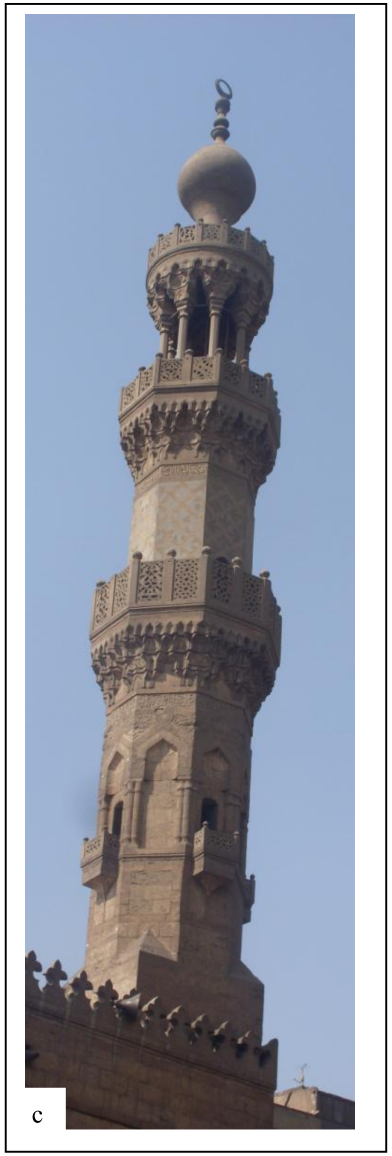
2.6.1.8. The Emergence of the Transitional Zone

Through the analysis of religious Mamluk architecture, it is possible to trace a fairly consistent occurrence of the transitional zones and the different architectural treatments used in these zones. These transitional zones can be seen in the facade design and in the plan design. There are four main fields of architecture in which they appear: the transitional zones of domes and minaret bases; on portals (for axis articulation or as part of stalactite corbelling); as wall articulation; and in the form of doorways, windows and niches.

Traditionally, from the structural point of view, the transitional zone between the rectangular walls and the circular or oval base of a dome has been regarded as either a squinch or a pendentive[22]. Besides the squinch and the pendentive a third type of transitional zone appears in Cairo in the second half of the 14th century and subsequently becomes quite common. It is a hybrid type and it will be called a "pendentive-squinch". Both geometrically and structurally it may be seen as an intermediate form, the lower part being a small squinch and the upper a pendentive, or vice-versa. One may briefly consider a type of transitional zone which only appears in Cairo in the late Mamluk period. This consists of an arch, either plain or of a shallow three-lobed type, placed diagonally across the corners of the square walls below the dome, but with curved stalactites instead of being filled in as a squinch. This treatment appears on 15th century portals (Fig. 2-56 b). In the case of squinches, it is the arch of the squinch which is structurally the most important element, and the stalactites are little more than a decorative filling, each tier resting on a stone corbel or a wooden plank set across the arch. In the case of pendentives, each row of stalactites is supported by a wooden plank set diagonally across the corners of the square walls of the base. Each row may be said to consolidate the row above; but it cannot really be said to support it [Ibrahim,1975]p.5-23

It was the Mamluks who commissioned some of the most daring examples of carved stone muqarnas, refining the motif into elaborate and deep semi-domes with stone pendants that hung over the entrances to monuments. These examples display not only the consummate skill of the builders but also their patrons' commensurate taste [Bloom,2000]**.** Muqarnasis almost composed of progressively projecting tiers of niche-like geometric elements, a three-dimensional pattern that in Mamluk buildings often decorated the deep hoods over portals, hid the squinches and pendentives that actually supported domes, and created a visual transition between such elements as the shaft of a minaret and the underside of the minaret balcony. Except for its use to decorate fine minbars, or pulpits in mosques, muqarnas was strictly an architectural technique, and it created a richly sculpted and textured visual effect. Like other elements of Islamic architecture, the broad appeal of the muqarnas may lie in its inherent ambiguity, for its geometric underpinnings delight the mind even as its visual characteristics delight the eye and inspire the soul. as shown in the following figures

[22] The principal functional difference between pendentives and squinches is that the top of the four pendentives occupies the entire circle of the base of the dome and thus directs most of the weight of the dome downwards to the four corners of the rectangular base. The squinch, on the other hand, being basically an arch across each corner of the rectangular base, draws the weight of the dome downwards through the four walls.



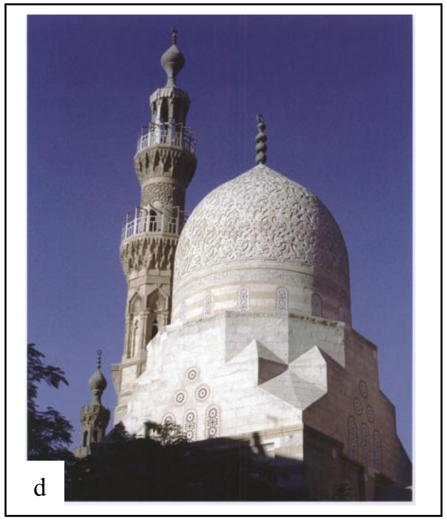


Figure 2-54: Different profiles in transition zones in Mamluk religious buildings.
a- The portal of Madrasa of Sultan al-Nasir Muhammad Ibn Qalawun,
b- The portal of Mosque of Ahmad al-Mihmandar,
c- The minaret of Madrasa of Qadi Zayn al Din Yahya
d- The dome of Mausoleum of Khayrbak.

2.6.1.9. Introducing the Funerary Structure into the City Urban Fabric

The burial chambers were erected in the Mamluk era on prominent sites inside the city fabric, and they affiliated them with public institutions, by connecting the memorial for the patron with the functional program of a socio-religious institution. But the building process of complexes involving different parts and stages of construction; i.e., whether a mausoleum was first built, then the religious building added to it or vice versa. In fact, historical evidence shows that both cases occurred. For instance, the Madrasa of Tatar al-Hijaziyya was added to the mausoleum she had built, while in cases such as that of the Madrasa of Sultan Qalawun and of Sultan Hassan, both the madrasa as well as the mausoleum were built simultaneously. There are also cases that show that a mausoleum was added to already existing mosques such as that of the Mosque of Aqsunqur (the Blue Mosque).

In general, tombs attached to complexes in the Mamluk period were given maximum exposure from the street by projecting the mausoleum into the surrounding space and by endowing the facade with a degree of transparency. Gaining visual dominance by projecting the mausoleum into public urban space was an idea that had been introduced when the first of the mausoleums, that of al-Salih Najm al-Din, was built for him by his widow Shajar al-Durr in 1250 A.D. and attached to his madrasa [Al-Harithy,2001]p.83. This idea was then continued during the whole of the Mamluk era as shown in the following figures.

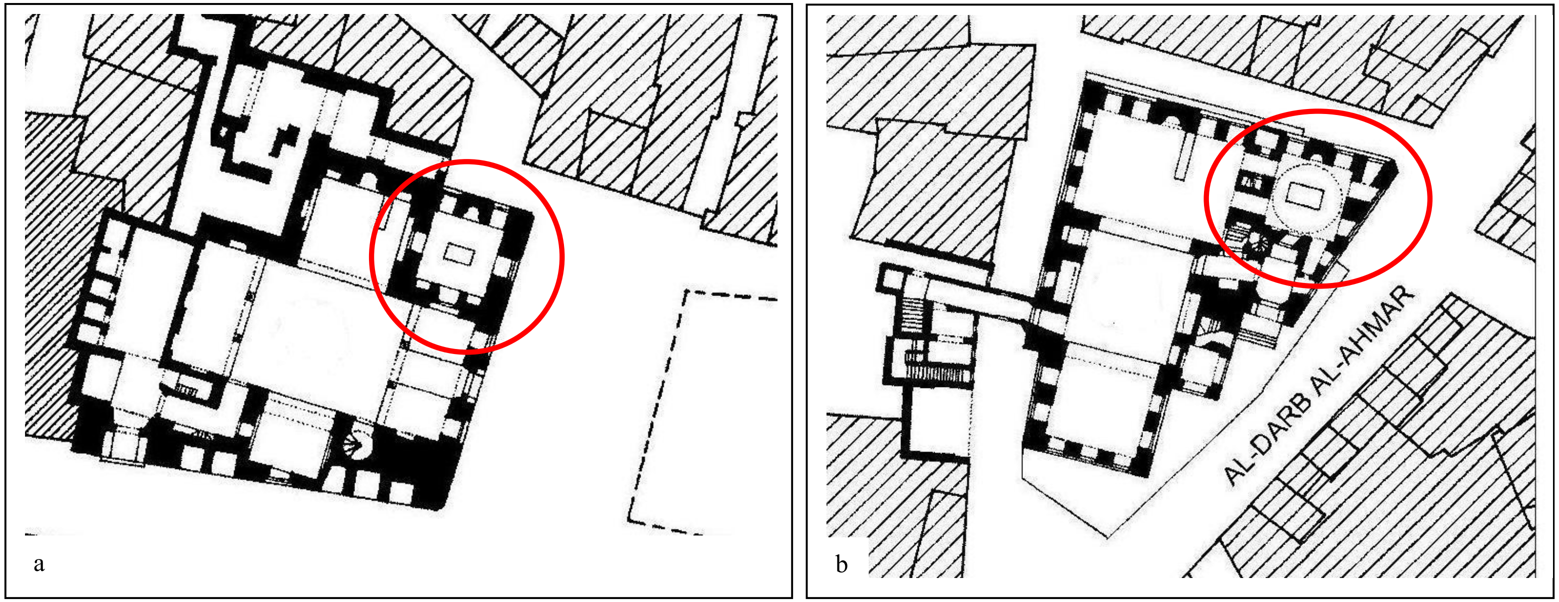


Figure 2-55: Projecting the mausoleum into public urban space
a- Mosque of Amir Aslam al-Silahdar, b- Mosque of Amir Qijmas al-Ishaqi.

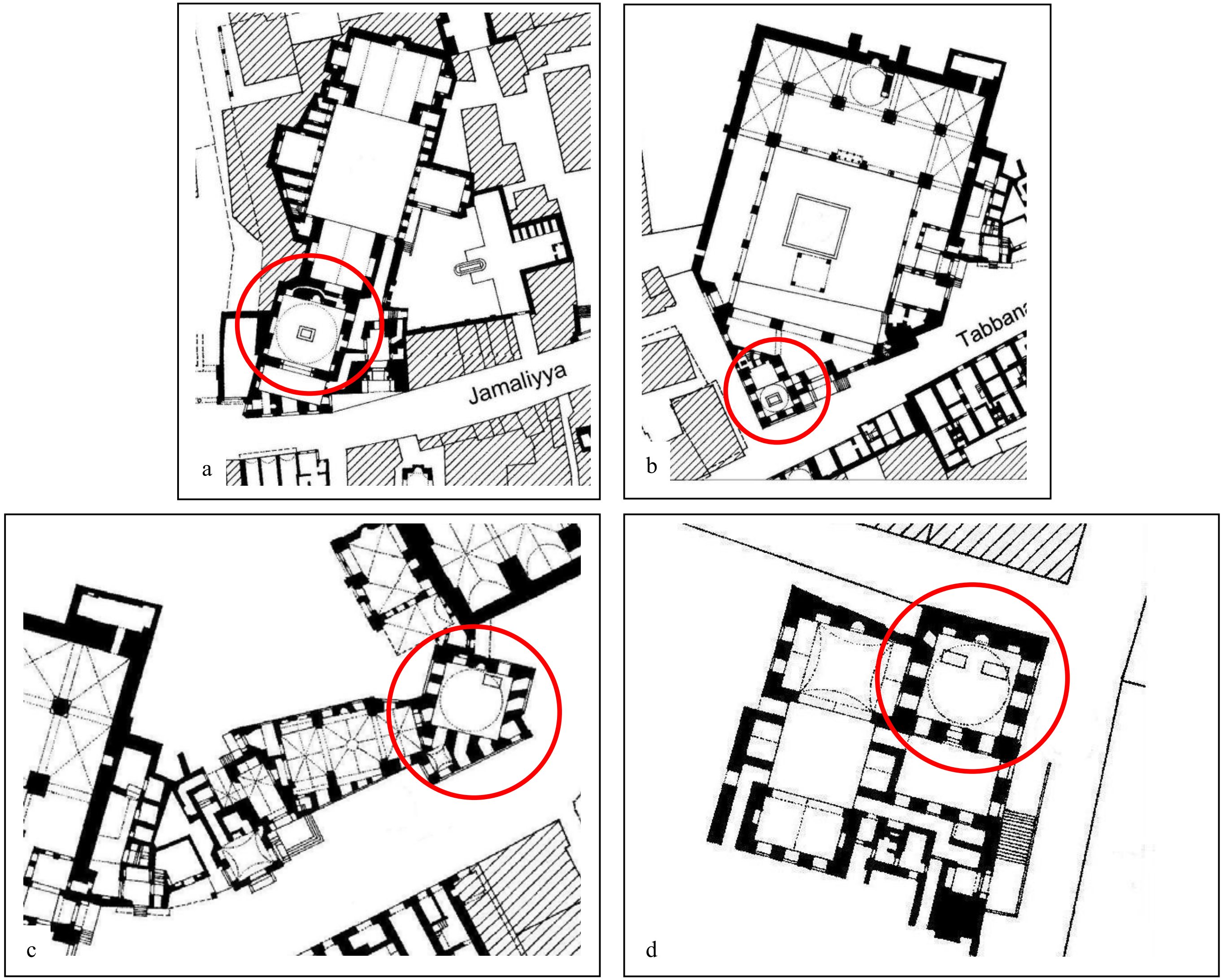


Figure 2-56 Projecting the mausoleum into public urban space
a- khanqah of Baybars al-jashankir, b- Mosque of Amir Aqsunqur al-Nasiri.
c- Madrasa of Amir Khayrbak, d- Mosque of Amir Qanibay Qara.

2.6.2. The Effect of Urban Context on Drawing the Relationship between the Architectural Vocabulary Elements of Mamluk Religious Architecture

When analysing Mamluk religious architecture it was found that many factors control the relationship between the building's architectural elements[23], such as the political, social, or religious factors. The most important factor is the effect of the urban context in drawing the mutual relationship between different architectural elements in the same building and in drawing the mutual relationship between the same architectural elements in different buildings along the same street. The Mamluk architect depended on studying the mutual relationship between his building's architectural elements and their distribution in the surrounding urban context, in order to emphasize his notions besides respecting the effect of the urban context on the building design. From his studies of these mutual relations he could determine the position of his architectural elements inside his building design. The urban context of the city forced the Mamluk architect to encompass many urban values in his religious building design; some of these values and how the Mamluk architect reached them in his religious building design will be shown as follows:

1- Respecting the Mutual Relationships between the Building Elements and the Surrounding Urban Context

When the Mamluk designer selected the position of his building's architectural elements in general and those which are in relation with the urban context in particular such as the dome or the minaret, he tried to draw a suitable and harmonious relationship joining them with the surrounding urban context. This is very clear in the complex of Qalawun: The projection of the madrasa section of the complex into al-Mu'izz Street complements the mausoleum of al-Salih and gives the space between the two complexes a sense of enclosure, also the entrance portal is placed opposite the entrance to the mausoleum of al-Salih to generate a zone of movement across the main avenue. Another example is the complex of al-Ghuri. If one looks at the two parts of the complex, it can be seen how the Mamluk architect played with the building masses in their urban level to generate a space between the two parts of the building and have a sense of enclosure. Also in the Mosque-khanqah of Emir Shaykhu al-Umari and the Mosque of Aqsunqur, the architect divided the building into two parts and placed them facing each other across the street. However, the two parts are in a very harmonious spatial and a visual besides geometric mutual relationship.

2- Making Visual Relations between the Building Inside Spaces and Urban Outside Spaces

The Mamluk architect tried to transfer the outside city environment into the building inside, by creating a strong visual relationship between the inside building spaces and the outside urban spaces. He did this in two phases. The first phase is the courtyard as an open space which plays the role of a city centre. The second is the visual connection between the building's

[23] The religious buildings contain five main different architectural elements - the courtyard, the prayer hall, the mausoleum, the minaret and the dome. In the next chapter the spatial, the positioning, the forming relationship beside the geometric relationship between them is observed in details.

inside spaces and the external urban elements, like the visual connection between the inside courtyard space and the outside urban elements such as the minaret or the dome.

From the analysis of the Mamluk religious complex buildings cases, it was found that the buildings are centred about quadrangular courtyards, and the courtyard is a congregational space around which all the building spaces were assimilated, so the courtyard represents the heart of the Islamic traditional building besides its role as the city centre. From this centre, four pointed iwans (in the case of madrasas and khanqahs) or four riwaqs composed of rows of pointed arcades (in the case of the hypostyle mosque) are generated axially from the centre: the eastern and western in the axis of the qibla and the northern and southern perpendicular to it. From the interior of the courtyard, one can sees the soaring minaret with its geometric transformations easing visual ascension, as shown in the following figures.

a

b

Figure 2-57: The visual relationships in Mamluk religious buildings
a- The courtyard as an open space in the Complex of Sultan Farag ibn Barquq.
b- The visual relationship in the Mosque of Muayyad Shaikh,

3- Emphasizing Verticality

Emphasizing verticality is one of the most important urban values which the Mamluk architect tried to reach in all his complex buildings through the use of the minaret or the vertical recesses in the building facades. Nowhere in the Muslim world can you find such a profusion of domes and minarets as in Cairo, they dominate the city's skyline. Minarets, indeed, are Cairo's joy and ornament and the source of Cairenes' favourite nickname: "Madeenet el Alf Midhana," "the city of a thousand minarets" [Feeney,1985]. The location of the minaret is almost above the entrance composition or immediately above one of the sides of the portal, as shown in Fig. (2-58c), and it can always be viewed from inside the courtyard. As a result, in Mamluk Cairo one often finds several minarets on the same street; they never seem to obstruct each other; on the contrary, they seem to come together, providing what seems to be a natural contentment to the eye of the beholder.

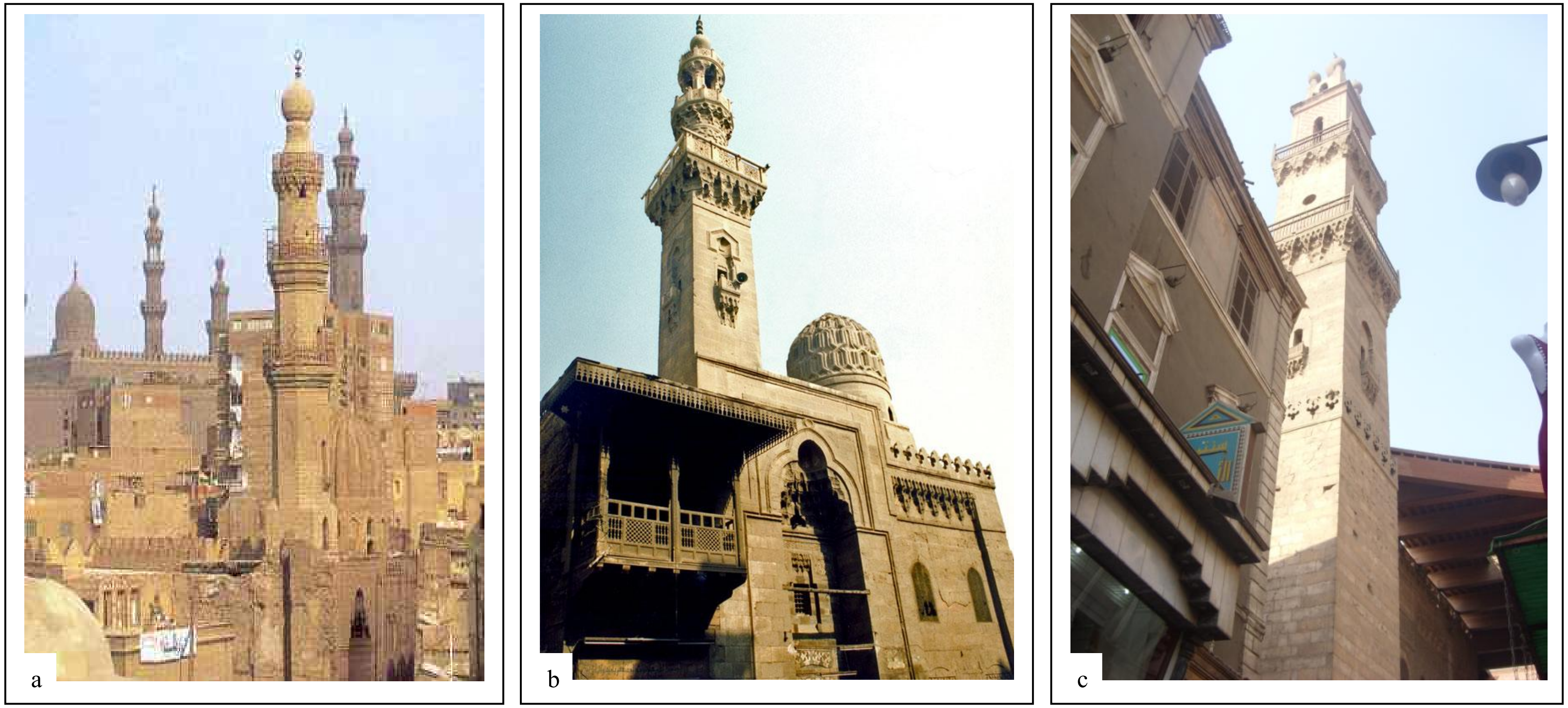


Figure 2-58: Emphasizing the verticality in Mamluk religious buildings
a- Minaret panorama in Mamluk cemetery, b- The minaret and the dome from the street in Mosque of Taghribardi, c- The Minaret of Al-Ghuri from the street

4- Designing the Landmarks

The Mamluk architect dealt with landmarks as one of the important elements in drawing the city's visual image. They mainly depended on the position of the minaret as the strongest landmark for the pedestrians. Great care was also taken in the location of the mausoleum chamber. It usually occupied a space overlooking the main street or square, as shown in the following figures.

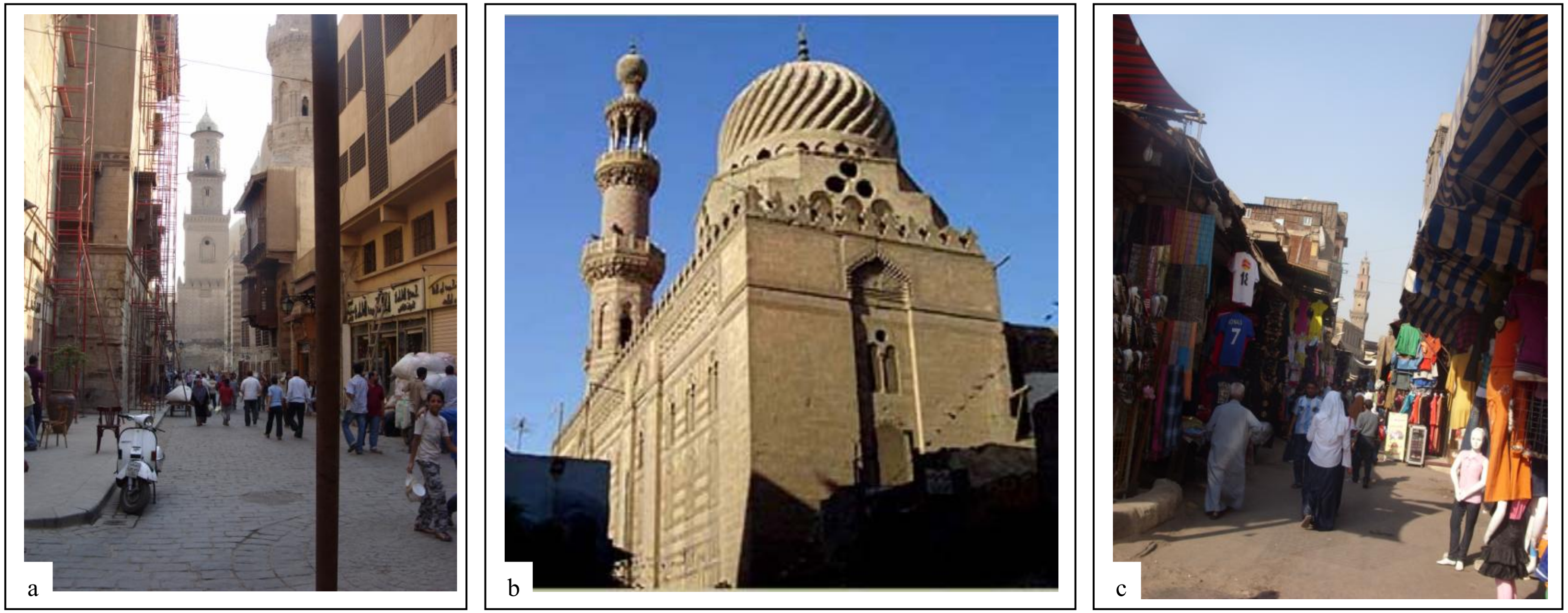


Figure 2-59: Using the minaret as a landmark for the pedestrians in Mamluk urban context.
a- The Minaret of Qalawun Complex, b- The Minaret and the mausoleum of Iljay al-Yusufi Madrasa, c- The Minaret of al-Ghuri Complex,

5- The Homogeneity and Unity of Spaces

The Mamluk architect tried to reach the unity of spaces through the strengthening of the relation between the inside and outside spaces and emphasizing the inward or outward in every space individually. This is seen very clearly in the entrance or in the courtyard composition and in the selection of the mausoleum location inside the design.

a- In the entrance composition: The entrance is the main point of focus in the facade. It is strikingly represented by a set of grouped elements that are inter-related, punctuating the austere walls of Mamluk religious buildings. The prototypical entrance involves a flight of rising steps which lead to a pointed niche, culminating in a group of stalactites, followed by a row of crestings, and topped by a towering minaret. By examining this characteristic entrance composition, it was found that the steps form the first element that takes the sight of the viewer upwards. These are usually either outside or within a pointed arched recess, which further draws the eyes of the viewer upwards, along the vertical straight lines (the terrestrial) to join with the curved parts (the celestial) to culminate in a point at the summit of the arch. As shown in the portal of the mosque of Aslm al-Silahdir it is pointing upwards.

b- In the courtyard composition: looking at the whole internal composition from the centre outwards, it is found that the courtyard as a centre point and from it a four pointed iwans (in the case of madrasas and khanqahs) or four riwfiqs composed of rows of pointed arcades (in the case of the hypostyle mosque) are generated axially from the centre. They were realized by making the iwans or riwaqs slightly smaller than the side of the courtyard, which visually gives a sense that it is a space related to the courtyard, generated from it, yet not part of it. That reflects the degree of homogeneity between the elements and they are reinforced when they are seen in combination.

c- In the mausoleum location: The mausoleum was designed for the teaching of Islamic law and religion and the reading of the Qur'an. So its location in the building design must be in a part which can be easily recognized from outside by pedestrians. This strengthens the relation between the function of the inside space and the outside urban space, as shown in almost all designs.

2.7. Conclusion

To show the historical background the chapter began by presenting how Mamluks came to power in Egypt then focussed on their scientific, religious and artistic life. Then the chapter focussed on Mamluk religious architecture by presenting the types of buildings and its architectural language vocabularies, and how the Mamluk architect could with the use of these different vocabularies form the Mamluk religious architecture style. Because there is no doubt that the Mamluk architect had prepared for his profession in a scientific and programmatic way and also that the highly sophisticated geometry used in building design did not come about randomly or by chance, the chapter went on to present the Mamluk educational system by focusing on the position of geometry science between the different curricula and teaching methods used. This was done to provide an understanding of the preparation process from when the learner was a boy until he became an architect during the Mamluk era.

In almost all religious buildings the Mamluk architect depended on complex forms and the complex composition of spaces. In order to understand the composition process in Mamluk religious architecture, the chapter presented the primary elements of space forming in Mamluk religious architecture and the geometric methodologies which he used in form composition and between them presenting in detail the symmetry methodology in form composition. In order to present the role of the urban context on religious building design the chapter went on to demonstrate the effect of the urban context on drawing the relationship between the architectural vocabulary elements, and by presenting the urban values which the Mamluk architect tried to encompass in religious building design.

From discussing the previous points the following comments can be presented:

- Mamluk religious, scientific and artistic life was characterized by the very high degree of sophistication, which was reflected by the establishment of the numerous architectural masterpieces they left.
- By analysing and focusing on space and form making in Mamluk religious architecture it was found that the designer had a very high awareness for the primary geometric elements of the space forming, which led him to generate a successful complex geometric composition in building design.
- The Mamluk designer had his methodology of symmetry in form composition besides his respect of the effect of the urban context on his form composition of the complex religious building in general and on the relationship between the building architectural vocabulary elements in particular.
- From the analysis of the educational process in the Mamluk era it was found that most of the Mamluk architects (mu'allimin) or master craftsmen, the builder, and all those involved in the craft of the building who were exposed to geometry either directly by having learnt and practiced geometry in a Mamluk education institution or indirectly by being part of the traditional Mamluk society, must have reflected their geometry learning in their creation "creations" through the geometric order inherent in the design method and construction process.

The next chapter shows how the Mamluk architect could use the geometry as a main domain helping him in his design of complex religious building and in particular in madrasa building design.

Research Skeleton

Design Method

Geometry

Islamic Architecture

Introduction

The first part | The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part | The Analytical Study and the Field Study

Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A | A Computer-Aided Generator for Madrasa Buildings Design

3. Chapter Three: Geometric Design in Madrasa Buildings

3.1. Introduction

The understanding of the significance of the creative Mamluk architects depended on the qualitative and quantitative physical understanding of form, space, shape and geometry. Geometry is the language of architecture. Since the earliest of times, architects have relied on mathematical and geometrical principles. In Mamluk religious architecture architects and designers draw upon concepts of geometry when they chose particular geometric forms to create pleasing and soul-satisfying spaces. Geometry lies at the very base of architecture so the Mamluk architect used it as a vital inherent factor in design method to identify new architectural compositions. This chapter deals with several points related to the link between geometry and design methods in the Mamluk period, especially in the design processes of Madrasas. The first point that is dealt with is the design method of Mamluk religious architecture. This is followed by a demonstration of the role of geometry in madrasa building design. Finally, issues related to the geometric formal language of madrasa buildings are discussed.

In this chapter it is demonstrated how geometry controls all aspects of the building design process. The Mamluk architect used it as a main tool helping him in all aspects of the madrasa design: the formal aspects, the visual aspects, the spatial aspects and functional aspects

The formal aspects: by determining the geometric rules which control the position of every space (composition elements) inside the whole building layout.

The visual aspects: by determining the geometric visual relationships between the building elements (the entrance with the minaret, the minaret with the court, the court with the mausoleum, the entrance with the court, the ablution space with the minaret, ,...etc.).

The spatial aspects: by determining the geometric relationships between the positioning of every spatial element inside the building form with its neighbour (the entrance, the courtyard, the mausoleum, the dome, the ablution space) and studying the functional relationships between all these spatial elements.

The functional aspects: by studying the three-dimensional design of different spaces inside the building and determining the degree of suitability of the spatial form to its function.

The findings of this chapter are vitally important for three reasons: they show how important geometry was to the Mamluk architect, they allow the analysis in Chapter 5 of the architectural elements that constitute the design of madrasa building from the geometric point of view in both their apparent and inherent geometric dimensions, and finally they help in formulating the geometric generative technique of madrasa designs.

3.2. Design Methods in the Mamluk Era Architecture

In order to understand the design method in Mamluk architecture and the role of geometry in the design method of madrasa buildings, there are three main points that must be presented: the use of architectural drawings in the Mamluk period, the design process and the construction processes of Madrasa building.

In the Islamic world there are several early textual references of the use of architectural drawings, which have been assembled and discussed by Gülru Necipoglu. They fall into three basic categories. Firstly, there are depictions of architecture rather than architectural drawings, such as the drawings of two buildings in a Qur'an manuscript discovered in Sana'a, which shows the buildings simultaneously in plan and elevation. These would have nothing to do with the creation of architecture and served other purposes. Secondly, there are references to buildings laid out full scale on site, such as the laying out of the city of Baghdad by al-Mansur in 762 A.D. Writing a century later, al-Ya'qubi said the plan was traced directly on the ground. Another, slightly later account by al-Tabari said that the plan was delineated on the ground with ashes, cotton seeds, and naphtha and then ignited so that the caliph, standing at the centre, could get some sense of its form in three dimensions (an experiment that would be interesting to re-create). Thirdly, most problematic, are references to drawings on parchment or skins. When al-Mansur wanted to transfer the site of the markets of Baghdad in 774 A.D., "he then had a large garment brought, traced on it the plan of the market," replicating the details and ownership of the original. Similarly, the architect of the Ibn Tulun Mosque in Cairo, dated at 876 A.D., was provided with parchment onto which he could presented what is the building looked like, so that the ruler could understand the design. In the Islamic texts that tie the use of drawings to the construction of buildings. There are several references to historical rulers drawing the plans. The Ghaznavid ruler Mas'ud (1031-41 A.D.) is said to have drawn architectural plans on paper: "He built with his own knowledge of geometry and drew the lines with his own exalted hand." [Ghazarian and Ousterhout,2001]p.144. The beginnings of the use of drawings are unclear in the Islamic world. We can suggest, based on the scale and complexity of building projects, when they should have appeared, but the actual surviving evidence is considerably later.

As for the design process itself, there is enough evidence to be sure that some Islamic architectural monuments were first drawn in two-dimensional form before their execution [Tabbaa,1988]. Al-Balawi, a historian contemporary to the Fatimid period (969-1171 A.D.), stated that a parchment was used for the drawing of the Tulunid Mosque in Cairo (867-869 A.D.). He quoted the encounter between the Emir Ahmed Ibn Tulun and the architect as follows: "Ahmed (the emir) said, 'Come, what it you say about building the mosque is?' the architect answered, 'I will draw it for you to see with your eyes'. Ahmed ordered the parchments to be brought to him and the architect drew the mosque." [Lewcock,1978]p.132. Relying on the 20th century concept of the design process, one can speculate that the engineer builder (Muhandis banna') category of architects must have been the one responsible for the production of the bulk of buildings in Mamluk cities and their role was as translators and composers of building forms that comprised visual elements dictated by the patron, while naturally conforming to the canons laid out by tradition. Giving weight to this idea is the fact that repeating the forms and plans of previous buildings (which were usually simple) are repeated with only slight changes. The Mamluk designer was supposed to be able to see his identification with a primary purpose, have willingness to follow laws laid down by tradition and avoid all that was superfluous and non-functional. This fact explains two aspects related to the design process. Firstly, the stability and progressive continuity in the design process and architects' thinking process during the Mamluk era which extended for more than 250 years in Cairo. The second aspect is the similarity in the design of various traditional Mamluk buildings of the different functional types because the goal of the Mamluk architect and craftsman was to get as near as possible to a traditional model (prototype).

Besides the different kinds of sciences that were necessary in the apprenticeship of the Mamluk architect, there were other obvious practical roles that he played in the stage prior to construction itself. In first place, it was he who measured the land when it was purchased or leased. This had to be done very carefully due to the legal implications. He was the one responsible for drawing the plan on the ground. Nelly Hanna said: "They (the court records) tell us that when a building was to be built, its plan was drawn on the ground, probably to indicate the borders and the division of the parts of the building. It seems that this was done as each floor was built" [Hanna,1984]p.39. After the drawing stage came the construction process. The building construction process usually started with the choice of the building site, and the recruitment of skilled craftsmen was the next step. The collection of building material followed the recruitment of labour. A small amount of documentary evidence is available about the construction instruments and techniques used by construction workers and the general view of the tools used in the Mamluk period is far from complete. There is a reason to believe that the drawing of the plan on the site was carried out using compasses, ropes and pegs. This system allowed the builder to achieve straight lines, right angles and different forms of bisection, congruency and proportioning. [Gabr,1992]p.273-278. The sequence of the three stages of the design method is as follows: First, the idea is suggested in which the architect included the geometric principles of design. Second comes the stage of formulating the idea with drawings, with which through the help of these geometric principles he could translate the design idea into drawings, and third the construction process starts. This sequence explains how geometry was the hidden factor which helped the Mamluk architect to accomplish every stage and proceed from one stage to the next.

The design method of madrasa buildings in the Mamluk era is outlined with the following main points:

- The Mamluk architect design method was based on the following laws laid down by tradition and to avoid anything that was superfluous and non-functional,
- The Mamluk architect is known to have been well trained in science of geometry and calculation.
- The buildings were first shown what it looked like prior to their execution.
- In the beginning of the construction process the building plan was drawn on the land the building was to occupy by using compasses, ropes and pegs.
- The Mamluk designer took into consideration how a member of his society (pedestrians) perceived a religious building design.

3.3. Geometry in the Architecture of a Mamluk Madrasa Building

Geometry is the practice of forms through the measure and relationships, by which each form can be unfolded from a preceding one. It opens out the oneness, underlying all geometric forms and the inseparable relationship of the part to the whole, and continuously reminds one of the unity of all created designs. Geometric principles became familiar to medieval Muslim scholars through the Elements of Euclid, first translated by al-Hajjaj ibn Yusef ibn Matar in 790 A.D. Their acquaintance with applied geometry appears to have been through the works of Archimedes and the compendium of the Indian text Siddhanta [Gedal,2002]p.20.

Geometry is an underlying ordering mechanism that establishes a consistent language of form. The obsessive preoccupation with geometry in the designing and constructing of Mamluk architecture has contributed to the statement that it constituted "a form of design theory" in Egypt between the 13th and 16th centuries. Unfortunately, medieval master builders in the Islamic world did not write as Vitruvius in the antiquity did, or the Renaissance architects. Contemporary written sources are relatively silent about the geometry principles that informed the process of architectural design in this period. To reach a better understanding of the process one has, therefore, to consider extant buildings in the light of the few remaining historical resources that once acted as an intervening medium in the conceptualization and a dissemination of architectural knowledge. It is through analysing these buildings that one can begin to penetrate the language of geometric design in Mamluk architecture.

This section explores the geometry of madrasa buildings through the revelation of its strict underlying geometric grammar. In order to understand the role of geometry two main points are demonstrated. The first is presenting the geometric relationship between the architectural elements in the building design, and the second is demonstrating how to analyse madrasa building design and the geometric analysis in particularly.

3.3.1. The Geometrical Relationship between the Architectural Elements in Madrasa Design

Starting with the assumption that the perfectness of building composition comes from its intrinsic geometric qualities and geometric relationships between its components, so the more architects know about geometric tools and geometric design aspects, the more they establish perfect composition of buildings. This leads to saying that the dynamic manipulation of architectural composition is highly dependent not only on the designer's perceptual and cognitive abilities, but also on his good choice of geometric relationships between his compositions components.

The architectural composition of the madrasas involves several architectural elements which were composed together. By looking at these elements individually, their overall geometric effect in their specific context could not be exposed. Because nothing is more fundamental in design than the formation and discovery of relationships among parts of a composition, the Mamluk designer could enforce the desired spatial configurations of building components and spaces by using geometric relations.

In this section, not every possible set of relations between the architectural elements of the composition of madrasa buildings in Mamluk religious architecture is observed. The section is rather focused on the most obvious geometric relations[1] between five architectural elements – the courtyard, the prayer hall, the mausoleum, the minaret and the dome – in order to illustrate how these elements are organized and perceived by the viewer. The research concentrates on three types of geometric relationship between these elements in the building composition, the geometric positioning relationship, the geometric obedience relationship and the integration relationship.

3.3.1.1. The Positioning Relationship

In architectural design shapes are frequently constructed within some geometric context, which is at a basic compositional level set by some abstract organisational devices, such as grids (patterns of regulating lines), axes (regulating lines of specific importance), positioning relations and regulation or construction lines. This demonstrates how interrelated regulating geometric positioning relationships, as an organizing device in design conceptualization, could become much more useful and interesting when used not just as a rigid skeleton, but to regulate the behavior of a design idea and to maintain its essential structure as its composition parts are manipulated. Seven types of geometric positioning relationships which connect the formal elements in Mamluk madrasa buildings are presented as follows:

1- Connection Relations

From analysing madrasa buildings, two types of architectural elements used for connection relations were observed: elements for visual connection element and element for moving connection. The minaret and the dome were used as visual connection elements between the pedestrian and the building, but the corridors played the role of moving connection elements between the different building spaces. Fig. (3-1) shows the visual connection between the two parts of Al-Ghuri complex across the street and pedestrians. Besides that, the Mamluk architect concentrated on the visual connection between his building formal elements, for example the visual connection between the courtyard and the minaret, the visual connection between the minaret and the entrance and the dome, and the visual connection between the building parts across the street (in case of the building was divided into two parts across the street).

[1] It is important to note that the number of geometric relations is indeed quite large and cannot be determined in advance, so a fairly small set of carefully selected relations could provide an appropriate compositional repertoire. New relations could be defined as combinations of already defined relations.

Figure 3-1: The visual connection in Complex of Sultan al-Ghuri

2- Alignment and Adhesion Relations

The alignment relation can be very clearly observed between the building orientation and the street direction in the urban context outside the building. The adhesion can be seen very clearly between the sahn and the iwans inside the building as well.

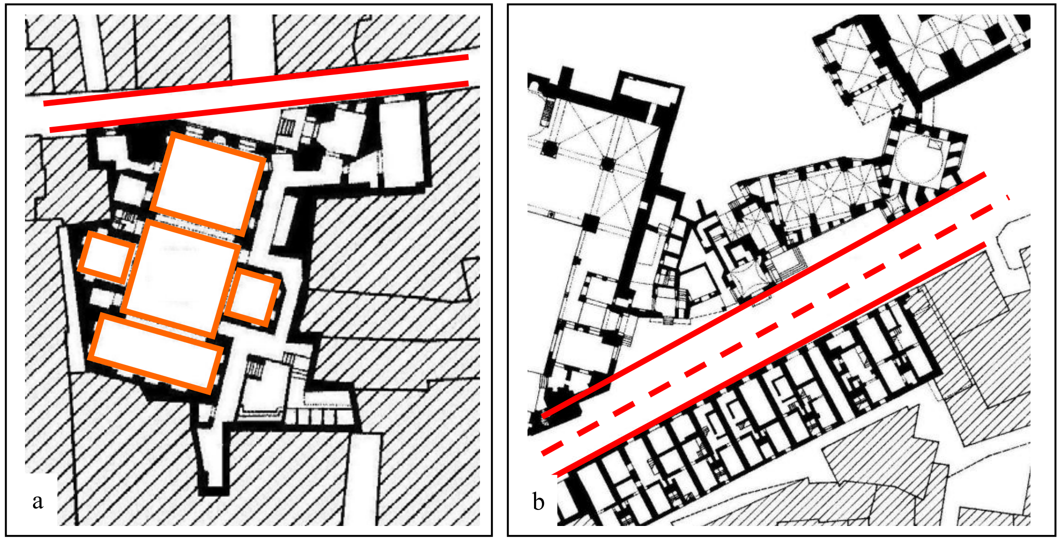


Figure 3-2: The alignment and the adhesion relationship in Madrasa buildings
a- The adhesion between the courtyard and the iwans in Madrasa of Sultam Jaqmaq
b- The alignment between the building and the street in Madrasa of Amir Khayrbak

3- **Proximity Relations**

When one looks at the madrasa form one finds the proximity between the functions linked together inside the same building and through the urban context.

Figure 3-3: The proximity of the similar functions.
a- In the urban context,
b- In the same building form, as in Madrasa of Sultan Hassan.

4- Parallel Relations

The parallel relation is always very clear between the building spaces orientation and the qibla direction. The parallel relations can be seen between the facades vertical panel as well.

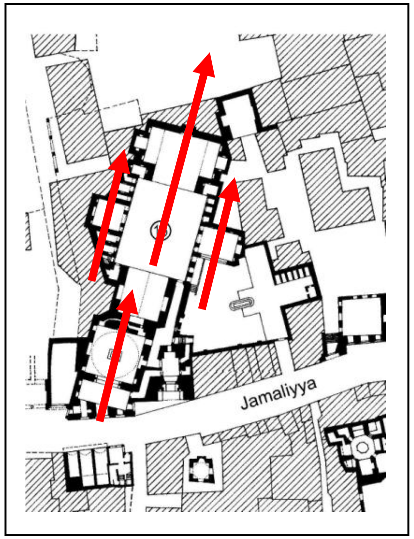


Figure 3-4: Parallel relation between building spaces orientation and the qibla orientation in Khanqah Baybars al Jashnakir

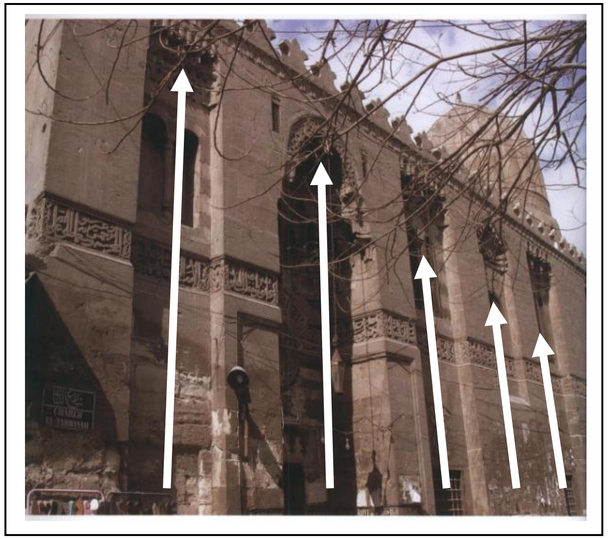
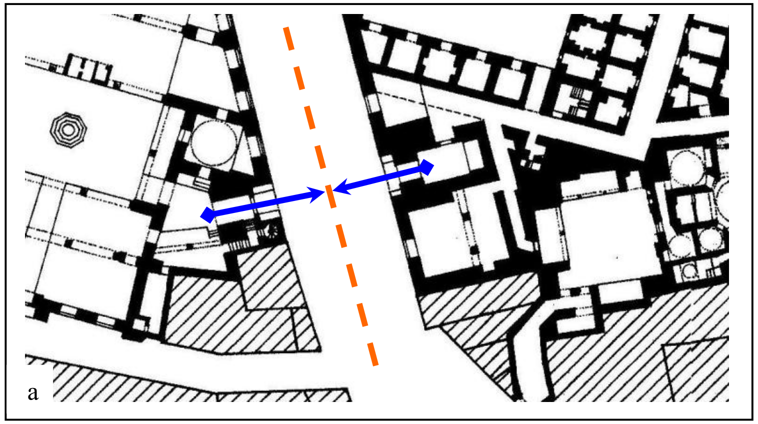


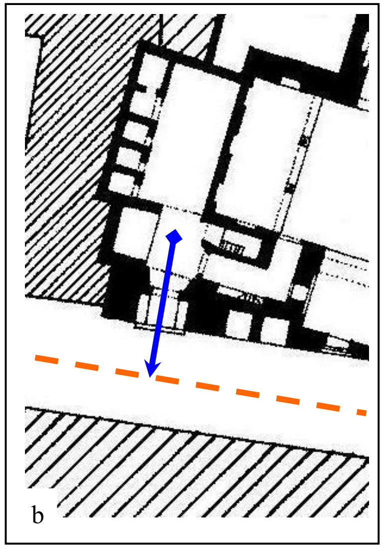
Figure 3-5 The parallel relation between the building facades vertical panel in the Mosque of Ahmad al-Mihmandar

5- Perpendicular Relations

The perpendicular relation can always be found between the street axis and the main entrance axis.

Figure 3-6: The street axis and the entrance axis and the perpendicular relation between them in the Mosque of Emir Azbak al-Yusufi.





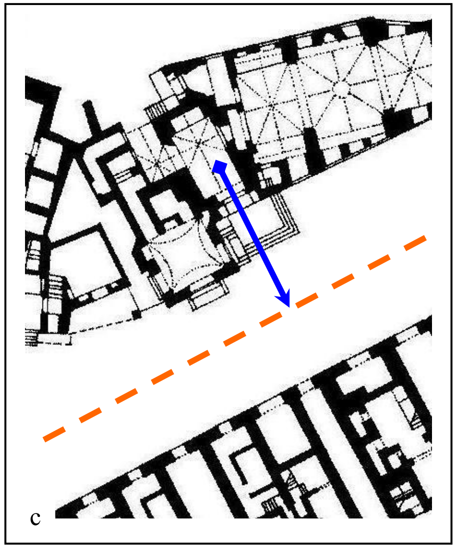


Figure 3-7: The street axis and the entrance axis and the perpendicular relation between them.
a- Mosque of Shaykhu al-‘Umari, b- Madrasa of ‘Abd al- Ghani al-Fakhri, c- Madrasa of Amir Khayrbak,

6- Angled Relations

The angled relation can be observed between the centre of the courtyard and the mausoleum.

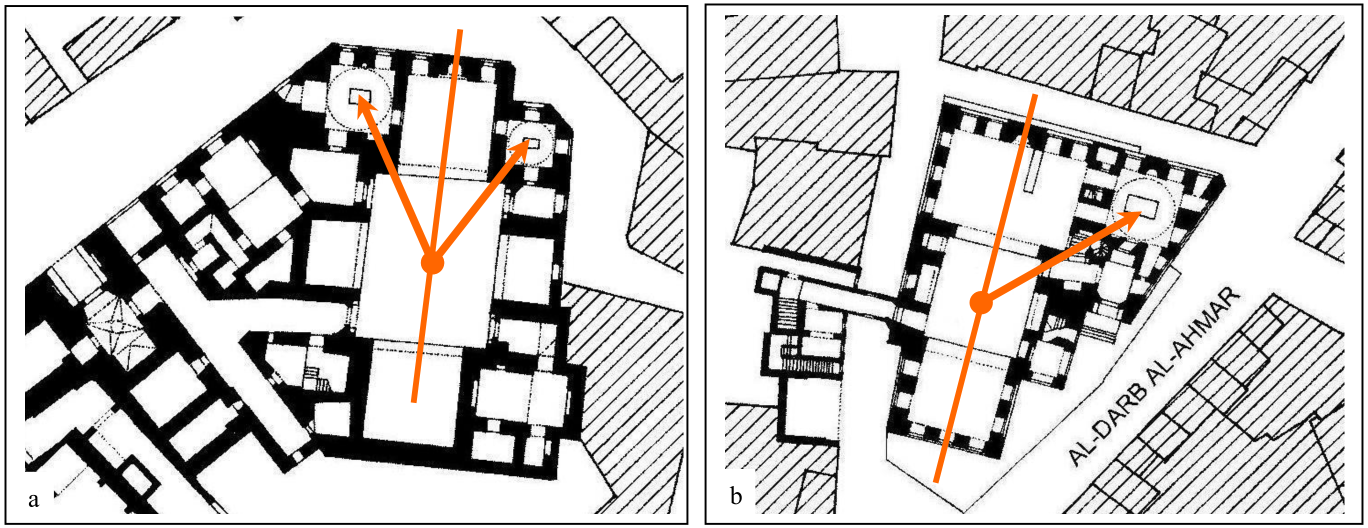


Figure 3-8: The courtyard and the mausoleum in angled relation
a- Madrasa of Umm al-Sultan Sha‘ban,
b- Mosque of Amir Qijmaa al-Ishaqi

7- Symmetrical (Bilaterally) Relations

As analysing the madrasa buildings, axis for symmetry is always found. This axis can be seen in the inside spaces (sahn, iwans) and also in the minaret design. All the building forms and the minaret composition are positioned around this axis.

The symmetrical relation can be seen in the building's spaces two-dimensional design, and also in the three-dimensional design, for example the geometric shapes of the four iwans are symmetrical and the volume is as well.

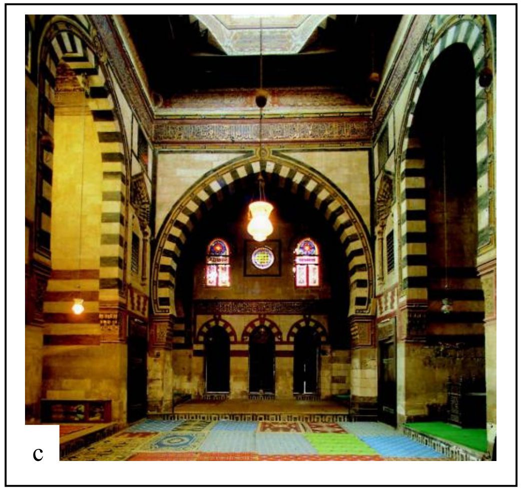
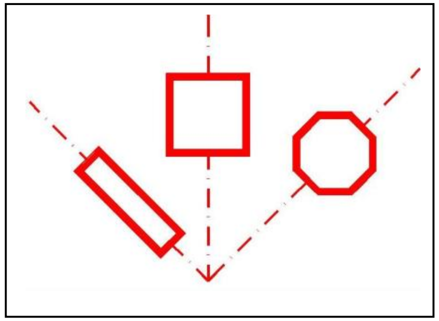


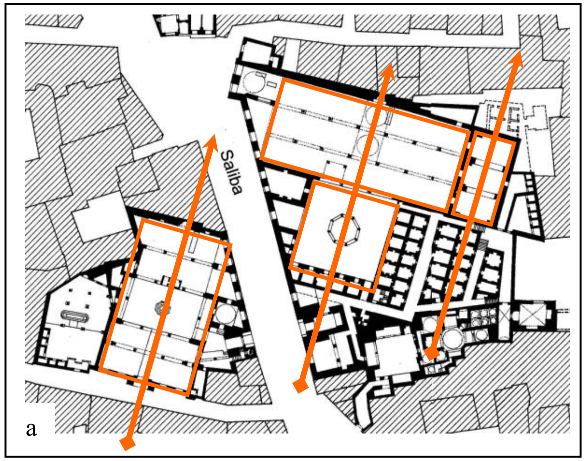
Figure 3-9: The symmetrical relations between the building spaces
a- The symmetrical in the minaret form in Bab Zuweila
b- The symmetrical relation in the dome volume in the Sultaniyya Mausoleum,
c- The symmetrical relation between the iwans space volume in Madrasa of Sultan Qaytbay,

3.3.1.2. The Obedience Relationship

This concept is the second type of relationship between architectural elements that are studied. It is a natural relation between geometric architectural elements. One could say that the idea of "obedience" is the participation of a geometric form with another, and a form "obeys" another form when it is defined partly or wholly in relation to a geometric element of it [Borie, et al.,1986]p.33. By allowing some elements to control positions and orientations of other elements through geometric relations and dependencies, designers can structure the behavior of the object being designed under future transformations in his design progress. It is possible to distinguish several forms of obedience, each corresponding to simple geometric relationships, five of which are mentioned as follows:

1- Obedience through Centralization (convergence of the axes). Ka‘ba is always the centre to which all the building spaces' centres are related.





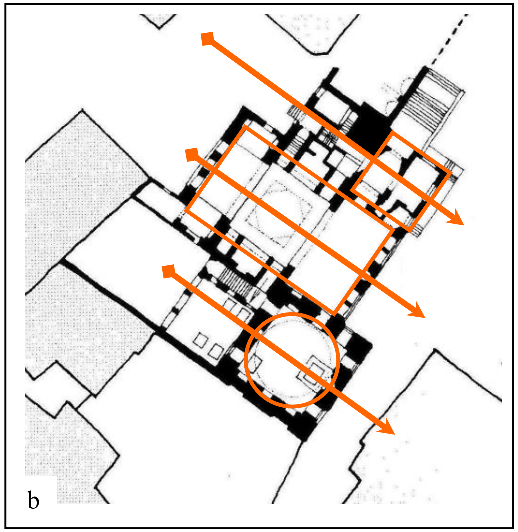
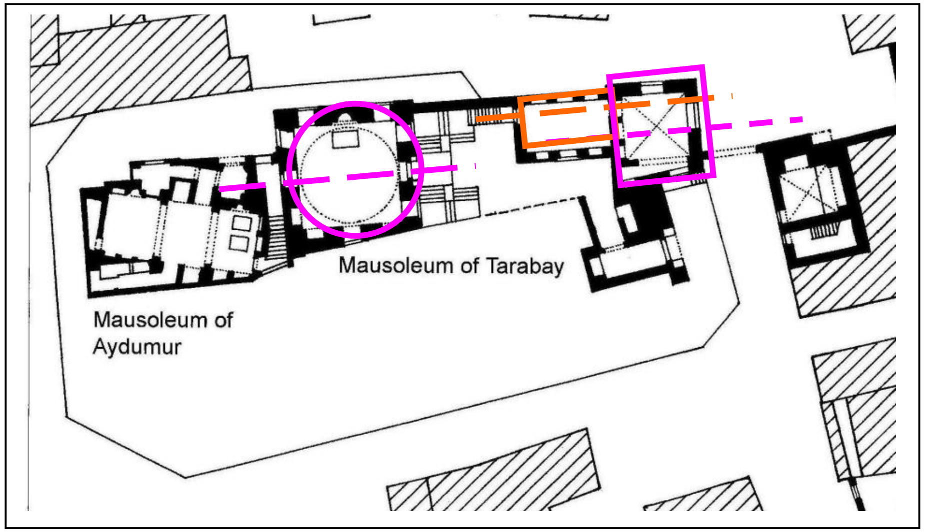


Figure 3-10: Obedience through centralization.
a- Mosque of Shaykhu al-‘Umari,
b- Madrasa of Sultan Qaytbay.

2- Obedience through Parallelism (Parallel Axis);



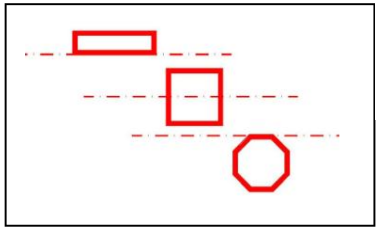
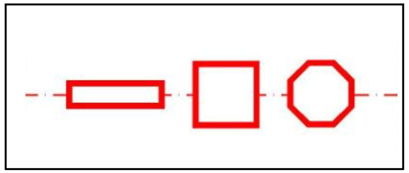
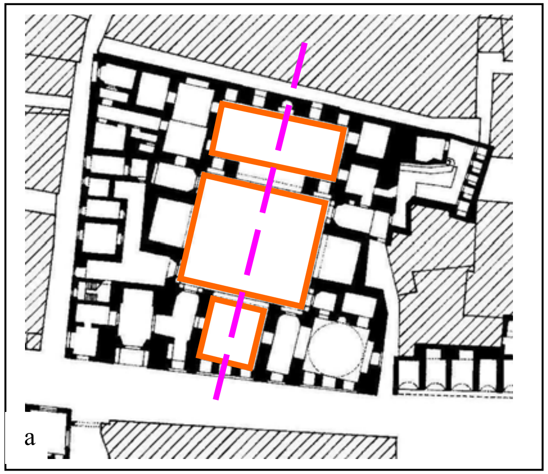


Figure 3-11: Obedience through parallelism in Mausoleum of Tarabay.

3- Obedience through Axialisation





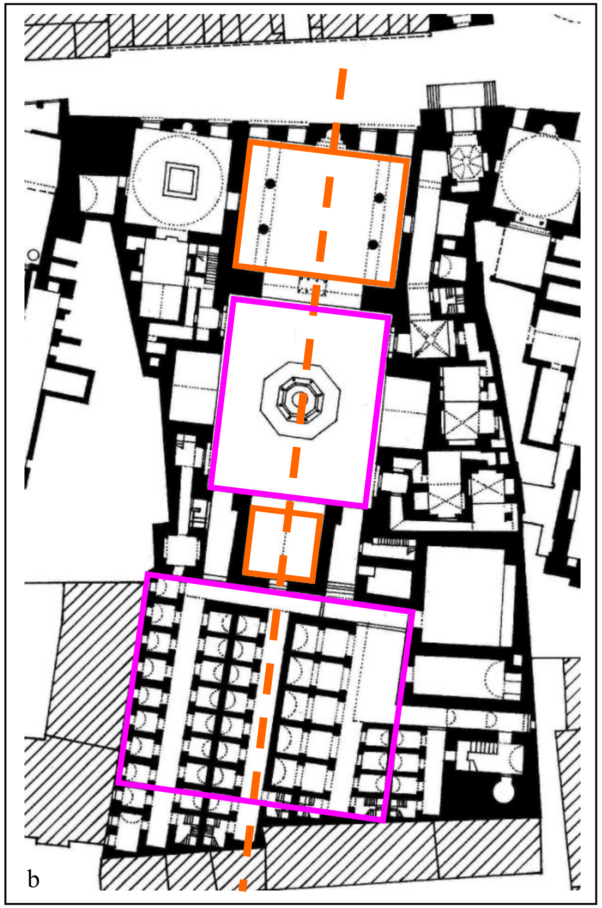
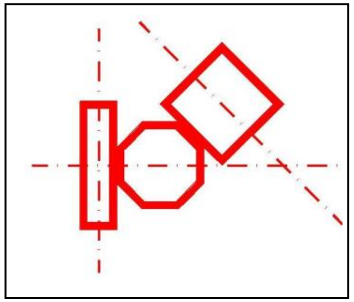


Figure 3-12: Obedience through axialisation.
a- Madrasa of Amir Uljay al-Yusufi,
b- Complex of Sultan Barquq.

4- Obedience through Tangency



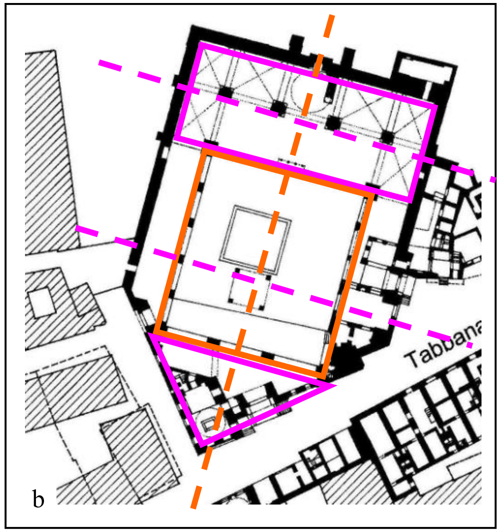
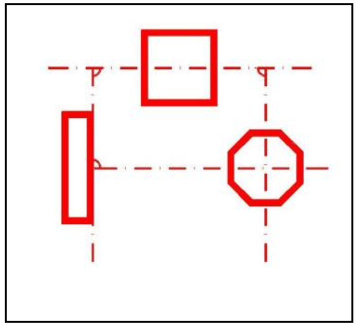
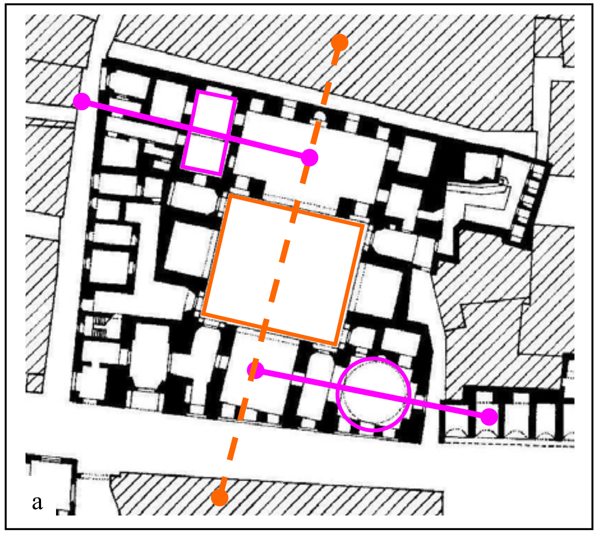


Figure 3-13: Obedience through axialisation.
a- Mosque of Emir Ulmas al-Hajib,
b- Mosque of Emir Aqsunqur al-Nasiri.

5- Obedience through Perpendicular





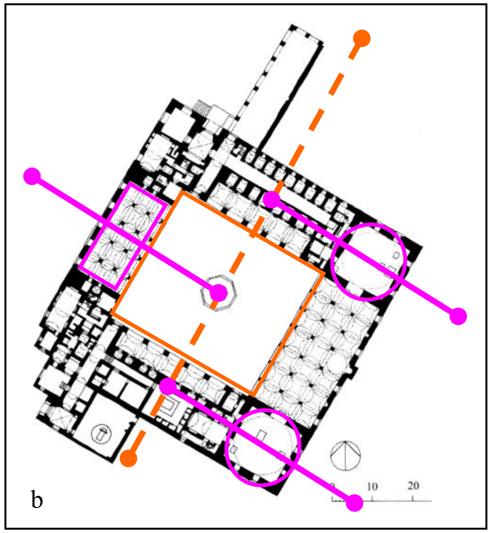


Figure 3-14: Obedience through perpendicular.
a- Madrasa of Amir Uljay al-Yusufi.
b- Khanqah of Faraj Ibn Barquq.

3.3.1.3. The Integration Relationship

This concept is the third and final type of relationship between formal elements discussed here. The relationship of "integration" can be founded between the geometric objects and the composition to which it belongs. More precisely, the geometric forms of the building are composed of shape relatively arranged to each other, so the integration relationship is the relationship between two or more geometric elements in terms of their ability to form a more or less coherent whole.
In this scenario, integration relationships define a compositional framework for establishing positions and relations of shapes and it seems possible to distinguish a large number of detailed integration between formal elements. Here three of the most common geometric integration relationship are presented [Borie, et al.,1986]p.39.
- **Integration by repetition**: the whole geometric composition consists of a serial assembly of identical formal elements. Each element plays the same role as its counterpart.
- **Integration by subordination:** the entire geometric composition is constituted by an assembly of dissimilar elements whose mutual relations are hierarchical. Each element may be a subject to an order superior to it, and may make a vassal.
- **Integration by unification**: unification is the form of integration that is most commonly recognized. This is one in which the component parts have no autonomy from everything and do not appear "detachable".

3.3.2. Geometric Analysis of the Architecture of Madrasa Buildings

Analyzing the architecture of madrasa buildings can be done in many different ways. There are three main categories or types of analysis. The first is the formal analysis, which shows a thin line that divides architecture from construction and it can also show architecture as an art. The second is the functional analysis, which demonstrates the "intention" of the architect, the design strategies and tactics and also the formal technique employed by the designer. The third is the geometric analysis, which mainly focuses on a decomposition and identification of formal elements. There are three points that characterize any method of analysis: the body of analysis, the system of analysis and the vocabularies used for analysis. The experience in Mamluk architecture has shown very quickly that in the case of madrasa buildings, geometric analysis system could be more relevant and the analysis focus on the succession of geometric shapes. It was thought, originally not to include a morphological analysis. Therefore, the method of analysis reduced the body of study to the building architectural form only, and also the urban forms are not included.

Geometric analysis reflects the building’s compositional difficulties, in turn, read the building’s compositions origins (for example, the presence of an initial form even though they were distorted but recognizable) and understand how they had been developed to reach the final compositions. The geometric analyses conducted revealed very clearly a consistent application of the spatial-geometric principles. These principles govern the building’s spatial organization, as well as that of some of the architectural elements, such as the sahn, the iwans and the entrance.

Geometric analysis, without becoming a compositional method can be applied in certain phases of architectural design. The geometric analysis progresses in stages: from the inside to the outside, from the small to the large scale and from the first stage of the analysis to a complex description of the plan. The geometric system is proposed in three stages. The first is decomposition and identification of formal "elements". The second stage is qualifying the nature of the different types of linking elements (positioning, obedience, integration as shown previously). The third stage is qualification of "modality" of these linking elements to generate the final form (integrity, deformation, articulation). It can be said that the geometric analysis system of any form means that the analysis form is broken down into "elements" on one hand and "links" on the other hand, and the latter ensuring consistency in all.

To make geometric analysis on the madrasa buildings, firstly, there are four aspects that must be discussed: the orientation, the axis, the geometric shapes and the centre point aspect. These four aspects demonstrate the building geometric composition and that will help understanding the geometric design of the building.

3.3.2.1. The Orientation

Monuments in Mamluk Cairo had to meet two often orientation differing needs: to face the street and to face Makkah to the southeast of Cairo. Taking into consideration that the streets were already laid out and could not be altered, this problem was rather easily solved by making the facade thick on one side and thin on the other and inserting a series of diminishing chambers and skewing the courtyard to the southeast. The orientation process directly affects the building's geometric characteristics. That the construction process depends on the rigid geometric principles for the orientations of the plans, confirms the fact that the Mamluks perhaps built within already marked-out boundaries.

The question which presents itself is how the Mamluk architect benefited from the orientation problem in his design and how it affected the building design process. The role of orientation in design process is explained as follows:

- The Mamluk architect benefited in the design from the orientation by depending on the qibla axis as the main axis in the building. Around that axis the building forms were articulated, so that there are always two main axes the Qibla axis and the perpendicular in all Mamluk buildings.
- The higher the importance of the space function, the more typically oriented it is to qibla direction.
- The contrast between idealistic orientation and a more practical one is most clearly realized in the madrasa building plan of Cairo, where the main entrance form is orientated according to the street directions and the main spaces of the building have their main axis offset according to qibla (direction of Makkah).
- The building orientation played an important role in organizing the exterior layout shape and the interior spaces. The efficiency of that role proceeded to affect the details of walls, doors, and windows. The fixed orientation of the building spaces is a clear method that encouraged the designer to start with the determination of the exterior layout. This point of departure is more efficient for controlling the overall shape, because the interior layout is more constant in its geometric shape.
- The orientation of buildings having other functions besides their religious function, makes the building more comfortable for orientation to the wind, ventilation and sun.

- The orientation is an integral part to the geometric design in Mamluk madrasa buildings because it affects by a direct or indirect way the spatial composition of the building (its direct effect comes on the spatial position of the entrance point of each space).

3.3.2.2. The Axis

The guiding force of the design of madrasa buildings were in the inherent geometric system. The design rationalism was developed on the basis of geometric principles, in which the use of the axis predominates.

The analysis of the main spaces in madrasa buildings revealed that there are always five main axes inside the building: the qibla orientation axis, the horizontal axis which is perpendicular to the qibla axis, the entrance axis, the two side iwans vertical axes, the horizontal axis to the qibla Iwan and the south iwan. These axes are shown in the following figure. The modular grid, developed from an axis and the angle, which became a systematic design instrument at all scales, has given the building design a powerful, dynamic and harmoniously unified form and the modular grid was developed with utmost sensitivity and imagination. It was flexible to adjust to the building site's changing situations.

The application of the axis and angles module in architecture of Mamluk was an old tradition in Cairo. For instance, in the design of the Sultan Qaytbay Madrasa (1474 A.D.), the plan was divided into five main centre points, which were determined on the basis of main five axes (Fig.3-15). The main centre point is located in the central space with related functions distributed in the remaining spaces axes.

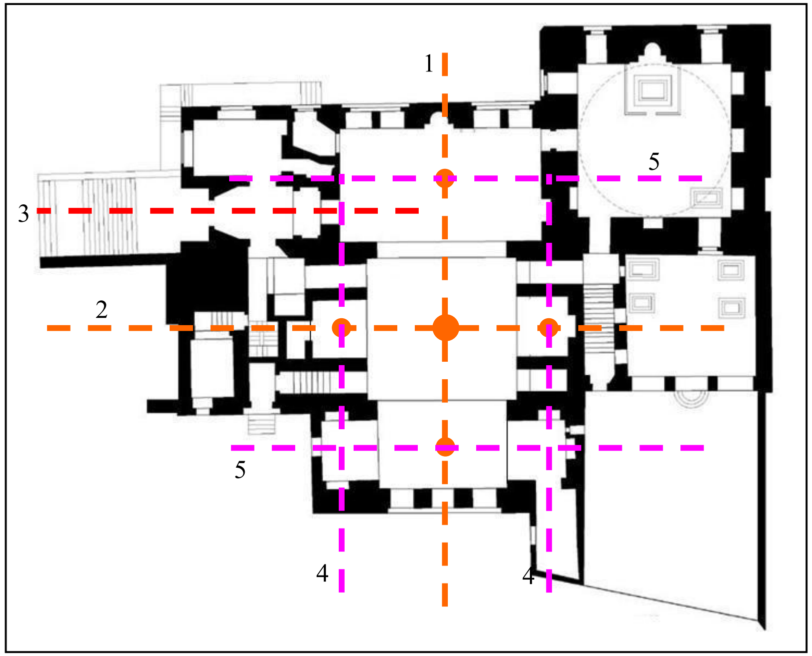


Figure 3-15: The main axes and centre points in Madrasa of Sultan Qaytbay

In geometry of interlocking axes (Fig. 3-16), the two major axes, A1 and A2, meet in the middle of the building, where the most important space, the sahn, is located at the meeting point and sets an order of interrelationships. The individual elements have their own axis and having been connected with the two major axes they play a subordinate but supportive role in an overall spatial organization. Axis A3 passes through the main entrance located on the right or the left of the court to meet the main axis A1, where the praying hall (qibla iwan) is located. The side iwans are located at the crossing of axis A4 with A2. Axis A5 starts from the side iwan centre point and extends towards the south iwan meeting the main axis A1 and determines the location of the south iwan centre point.

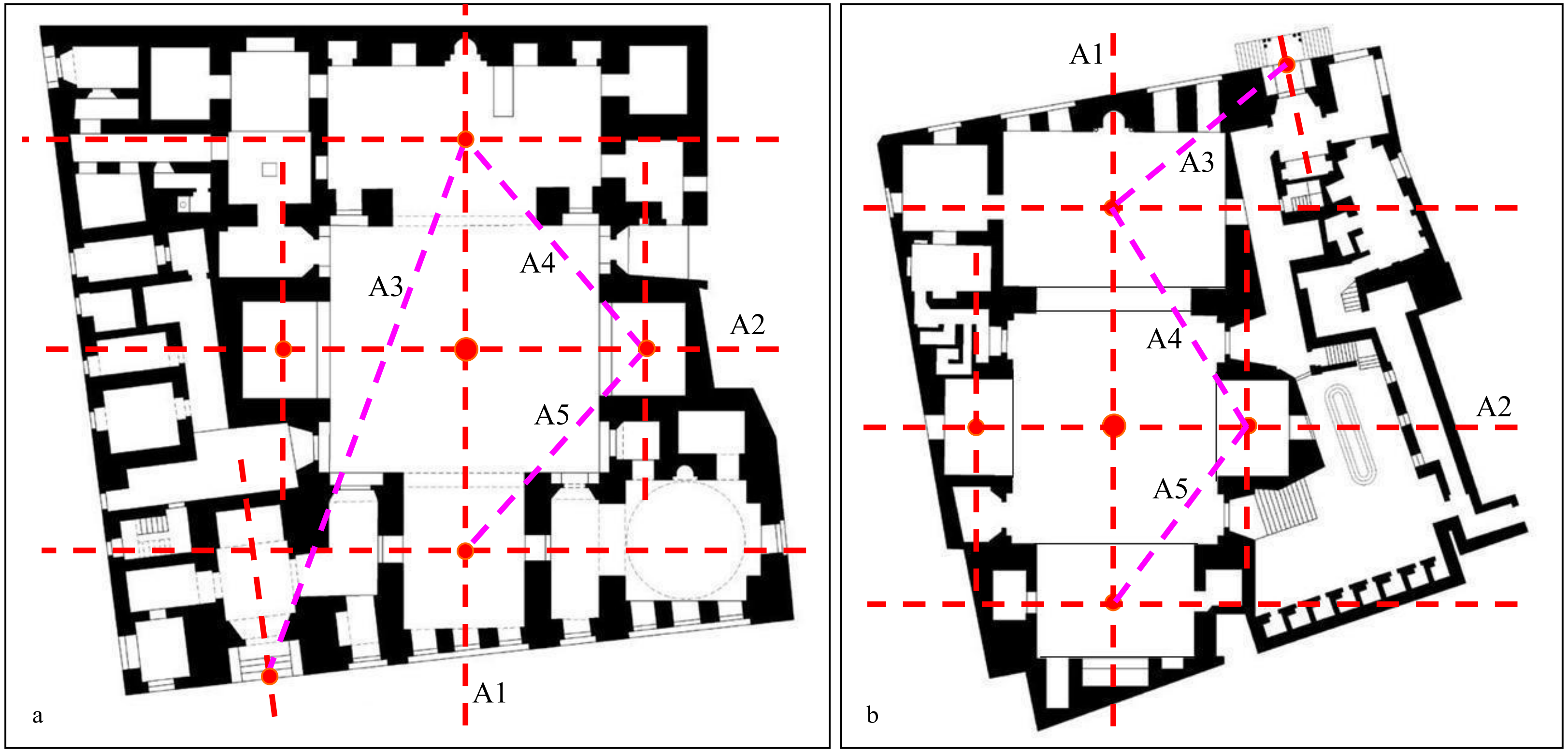


Figure 3-16: The geometry of interlocking axes in the design of madrasa form.
a- Madrasa of Sultan Uljay Al Yusufi, b- Madrasa of Sultan El Ashraf Brasbay.

The axis also defines privacy values by locating private functions such as student residences, halls and meeting areas in the central core and public activities on the periphery of the building complex. Axes, however, have not led to symmetry or to an identical visual perspective on either side. Although several of the buildings are symmetrical in design, their spatial setting is non-axial. In fact "they might be defined more as balancing axes than as symmetrical ones".

In conclusion, therefore, axes connect the buildings visually, giving a sense of unity and balanced co-existence within one ensemble. This leads one to say that there are certain angles connecting these main spaces centre points. These angles are changing according to the building site conditions.

3.3.2.3. The Geometric Shapes

The polygons are the elementary shapes of formal geometry. Individually or in combination, they are the basis for numerous plane figures, patterns, and designs important in architecture. In this regard, the geometric homogeneity between different shapes used for different functions are an essential part of design [Blackwell,1983]p.49. The emphasis in architecture is usually on the creation and definition of space for functional purpose. To produce designs that were functional as well as models of geometric composition, designers had to apply principles of geometry and had to use geometric shapes in their work, because geometric shapes provide perfect geometric proportions related to each part of a building with every other one and with the whole building form. Not all geometric figures are formed by straight lines. One of the most useful geometric shapes is the circle. The square and the circle, and their immediately related shapes are the simplest, most perfect and stable geometric forms found in Mamluk architecture. The application of square as a generic unit brings the relationship between all parts, from the smallest to the biggest dimension. It regulates not only totality, but also achieves unity in the overall composition.

No element plays as important a part in architecture composition as the geometric shapes. The following figures show the different kinds of geometric shapes which the Mamluk architect used in his madrasa design, and also the Mamluk architect manipulated the geometric shape not only in two-dimensional design but also his imagination extended to manipulate them in three-dimensional design.

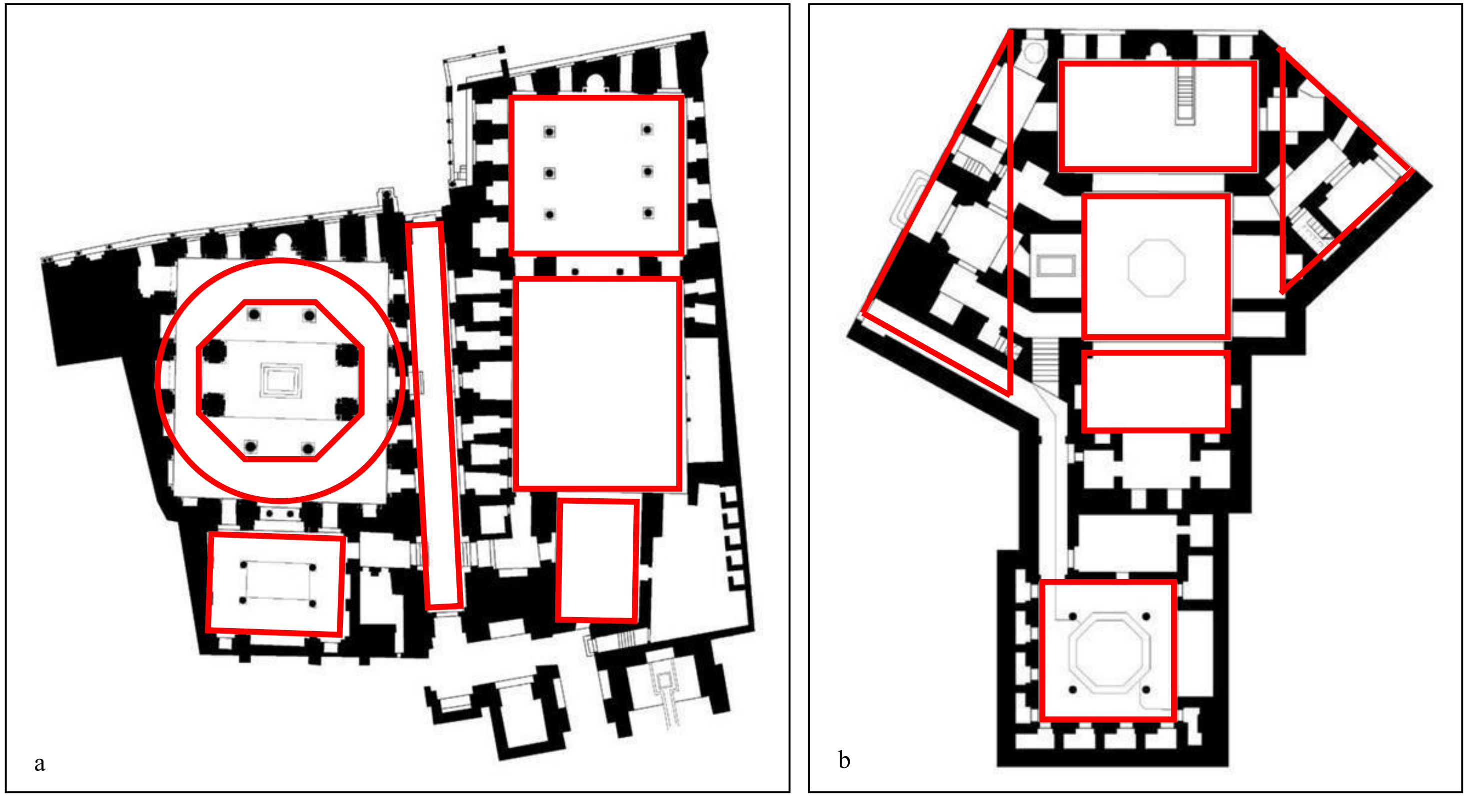


Figure 3-17: The geometric shapes in the design of madrasa buildings.
a- Madrasa of Sultan Qalawun, b- Complex of Emir Azbak al-Yusufi.

3.3.2.4. The Centre Point

In Mamluk architecture all processes of form generation are based on the transcendent principles of the growth of the point as unity (the point grows into the line, then to the plane, and finally forms the third dimension of a solid). Looking at the overall plan of the madrasa with its central sahn, the most logical starting point for any controlling geometry must be the centre of the sahn. It is here that the two main axes cross, and, as is the case in cruciform-planned madrasas, it was the visual centre [Walls,1990]p.41

The Mamluk religious buildings are centered on quadrangular courtyards which either have at their centres an octagonal water fountain roofed by a dome or have an abstract octagonal shape inscribing a circle in the marble flooring. From these centres, four pointed iwans or four riwaqs are generated axially from the centre: the eastern and western in the axis of Ka‘ba and the northern and southern perpendicular to it. The iwans are always smaller than the side of the courtyard, which visually gives a sense that is related to the courtyard, and generated from it. The courtyard represents the heart of the madrasa building and from it the whole geometry and order of the building come to be realized. According to that, the centre point of the main space is the important point in the building body, so it holds high importance in the building design process. The architecture design starts from it and all the building design forms are generated from it and related to it.

The essence of any form is not its visual final shape as much as the principles on which it was based. In Mamluk architecture the unity of space is achieved by the conformity of the orientation of the form components to the centre; it is that centre which generates and orders forces to the whole composition of the building. This point is vital to understand the importance of the centre as the point of beginning and end in the form conception and design process of Mamluk religious building. Not only the design process but also the constructing process had begun with determining the building main spaces' centre points on the site by using the compass and the robe with certain angles connecting these centre points, and takes the straight lines connecting the main spaces' geometrical form centre points as the inherent geometric shape in the design. This set of points is considered to be the element in question and then the main spaces boundaries can be determined, as shown in Fig. (3-18) below.

Such an understanding of the previous four aspects helps when demonstrating the geometric methodology of design and explains why Mamluk buildings turn inward and the interiors are the real architecture more than the facades. The Mamluk architect depended mainly on the interiority in the building design process. This supports our suggestion of intersecting axis from the main spaces' centre points encompassing perfectly the building main spaces and accordingly the building form. The madrasa design can be described briefly in six steps as the geometric basis of the analysis, they are as follows:

1- Determining the main building orientation axis in direction of Makkah, by using the compass, (vertical axis).
2- Using the compass in determining the main horizontal axis.
3- Determining the building main space's centre point (the courtyard (sahn) centre point).
4- Determining the building main spaces' centre points, by using certain angles connecting them with the courtyard centre point; they connect with each other by certain angles.
5- Determining the main spaces boundaries (the sahn and the four iwans)
6- Completing the design of the building by adding the rest of the building spaces.

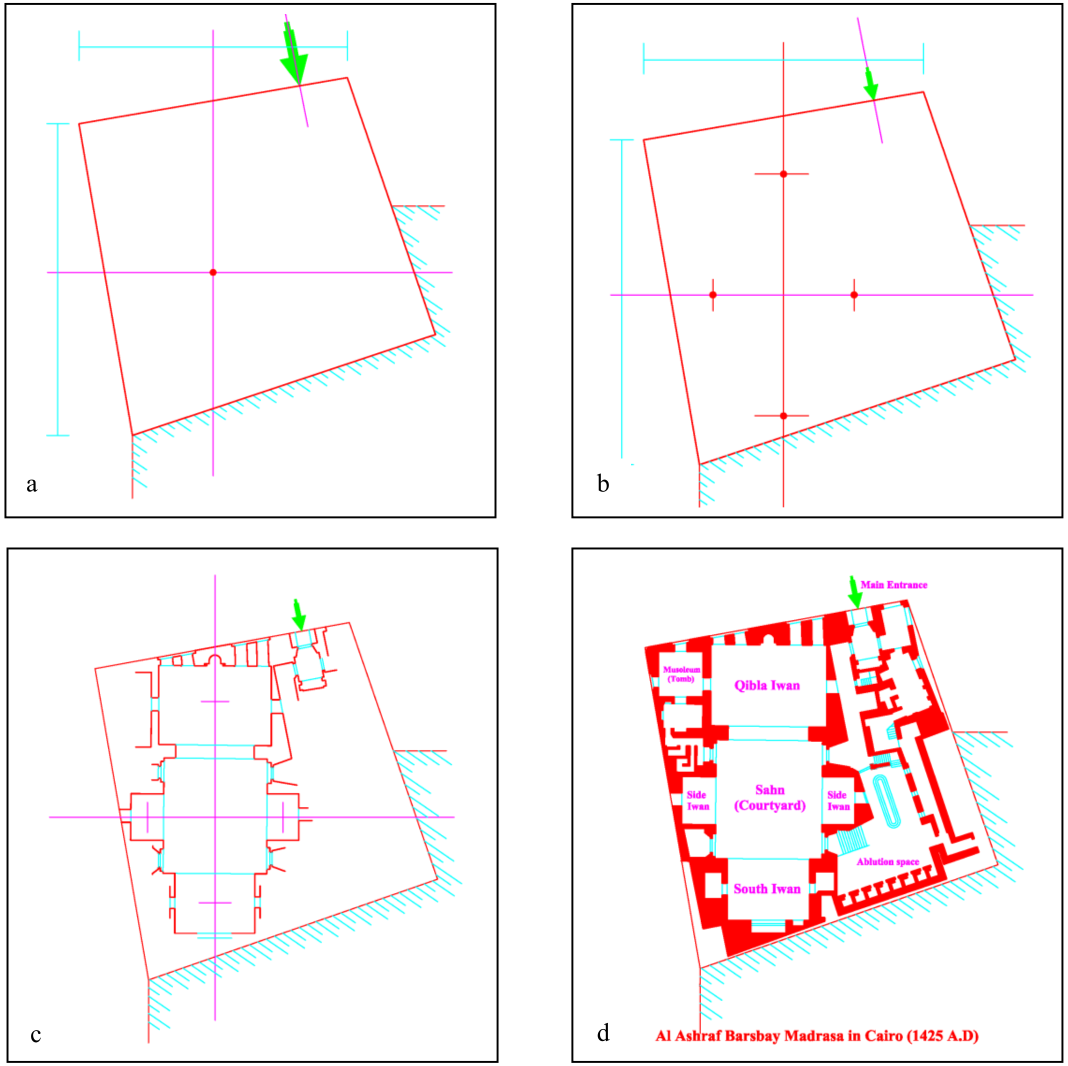


Figure 3-18: The designing process of the madrasa building applied in Madrasa of Sultan Barsbay
a- Determining the main centre point (the sahn's centre point), b- Determining the four main centre points, c- Determining the four iwans boundary, d- Completing the building design

3.3.3. Manifestations of Geometry in the Architecture of Madrasa Buildings

From the geometric analysis of madrasa buildings in Mamluk architecture it is found that geometry has four main geometric manifestations. Firstly, there is inherent geometric system govern and control the design. Secondly, the Mamluk architect depended on certain geometric shapes in madrasa design. Thirdly, the geometry has a vital role in the design process itself. Fourth and finally Mamluk architects depended mainly on geometry in their profession. These points are described briefly as follows:

1- The Hidden Geometric System

- One of the main reasons for the longevity of the Mamluk style lies in the visually nearly imperceptible interrelationship of complex forms derived from each other through a strict geometric process.
- The most deeply seated creative philosophy of the Mamluk architect was the ideal spatial realization and imitation of laws which were taught to govern the craft as well, keeping in mind that the Mamluk design is usually based on a geometric system which predetermines qualitative geometric criteria and principles for the creative design process in architecture.
- Even in the monuments of the early Mamluk the underlying geometric disciplines were completely glossed over (inherent and not obvious), perhaps because this interlocked type of design was used in hundreds of stone structures which make the geometry disciplines unremarkable.
- There is an inherent scheme controlling the design of complex religious building. The design starts with determining the centre points, as a references points of the building main spaces, and then by using the geometric operation (symmetry, addition, subtraction, rotation,…etc) the designer can generate all the building design. The main centre points play the role of the quickly available reference points for the guideline system of design.
- The overall plans were followed by key designs for secondary parts which are as puzzling as they are orderly.

2- Geometric Shapes in Building Design and Construction

- There are certain polygons – the principal units which govern the geometric development of the Mamluk design.
- The first and most central design shape was the square and its derivatives. It was used not only as an additive module, but also in rotation. Then it was as the generator of a dynamic and directional system underlying the designs of the complex buildings.
- The circle and its segments played a fundamental role in all dome and vault projection methods. The projection method for the dome and vault construction, which is drawn on segments of circles as the service unit is considered the most important element of construction methods.

3- Geometry in Design Process

- The design process and the construction process were based on the geometric progression of the inherent geometric system.
- The geometry has an important role on making the design process starting from the interior and move to the exterior in generating the building design.
- The geometry helped the Mamluk architect to generate his building design in a systematic way. That systematic method could be applied to any other building site to generate the building design as long as it is related to the same categories of buildings.

- The design by using geometric axes became the main practical and aesthetic key for Mamluk architecture. The process is simple, unemotional, speedy, easily transferred to the tracing floor and easily checked out during construction.
- The architects' use of the system of geometry liberated them for a wide variation of personal styles and themes.

4- The Role of Geometry in Mamluk Architect Profession

- The Mamluk architects signed themselves as mason (banna), engineer/geometrician (muhandis), and stucco-worker (jissas) interchangeably; which means the erection and decoration of a building were carried out simultaneously by a team of specialized geometers, builders and artisans working under the instruction of a supervisor trained in all the building trades.
- The master builders (architects or muhandis) were responsible for coordinating all stages of design process. The Mamluk architects had a universal role in supervising all aspects of architectural design including construction and decoration; this explains why building plans have a curious juxtaposition of designs for two- and three-dimensional ornaments.

This section illustrated the role of geometry in madrasa buildings as an example of Mamluk architecture; it has demonstrated that geometry was the sole determinant in design and its rules were never bent or superseded to accommodate the functional requirements of the building or the vision of the patron.

3.4. Formal Geometric Language for Madrasa Architecture

Understanding the geometric formal language, which for centuries has provided the basis for Mamluk architecture in light of geometric analysis, allows the observation, through the analysis of the formal data, of how small elements are inserted in a continuous and coherent whole form composition. If madrasa buildings are interpreted geometrically, there will be no distinction between the essential and the inessential. Every geometric shape is essential and, therefore, creates a greater coherence. It could be said, in this light, that the general form is not what counts the most, but rather what is really important is the way in which the parts hold together. What unifies these traditional madrasa buildings, sometimes bridging centuries and continents, is the "formal language", a minimum of common formal features whose persistence determines the longevity of the design, because it contains a set of architectural elements which lie at the architect's disposal and a number of operations or allowed compositional rules for combining the basic elements.

The geometric order is represented by ideal mathematical forms (in 2D: e.g., line, circle, quarter, or 3D: e.g. plane, sphere, cube) and ideal relationships (e.g., perpendicularly, parallelism, symmetry, rhythm/regularity) [Rubinowicz,2000]. In this geometric order, the geometric formal language is the important factor which stresses on the architects during the designing process to focus on the geometric properties of each space besides paying sufficient attention to the space function and the building final geometric form. Two aspects related to the geometric formal language are presented; the first is the geometric shape grammar in Madrasa buildings and the second is the geometric spatial design in Madrasa buildings.

3.4.1. Geometric Shape Grammar of Madrasa Architecture

The geometric shape grammar is the formal language for madrasa buildings. It is that part of the design study which deals with the morphology of the overall geometric forms of buildings and their internal structures and with the incremental geometric processes that generate them. It is concerned with the constituent components of a form and their arrangements and relationships. It consists of a set of rules that can be used to generate a set of designs and the language of designs generated by a grammar can be considered analogous to a design style. In the geometric shape grammar formalism, such spatial elements can be easily translated into 'shapes' that constitute spatial relations and the ordering principles can be translated into 'shape rules' that are responsible for the organisation of spatial relations. In light of that, madrasa buildings can be seen as a configuration of spatial elements bearing formal relationships with one another.

Madrasa buildings are square geometric spaces that change as one progresses through and up the building. They are a beautiful composition of stripes and straight lines of Mamluk architecture. The main function of the building is used not only for the display of worship, but also for education and living functions that are related to the Mamluk lifestyle. In order to understand the geometric shape grammar of madrasa buildings' architecture, three related points are demonstrated: the first is the geometric features of composition in madrasa architecture; the second is the compositional methods of geometric forms in madrasa architecture; and the third is the geometric patterns in madrasa architecture.

3.4.1.1. Geometric Features of Composition in Madrasa Architecture

The work of an architect consists in transforming spaces and function relations into geometric composition in geometric design. The principal mechanism utilized in geometric design activities was the use of regulating elements (regulating lines, points, planes and volumes) with the help of certain tools (axes of symmetry or of alignment, centres of rotation, points of intersection, and bounding lines) to regulate the overall design process. Although Mamluk architects freely manipulated (added and removed) geometric elements, they were able to preserve and maintain their underlying geometric order and even accentuate it through the use of such mechanism which helped them manage part-whole relationships, design hierarchy, morphology-geometry relationships, and scaffolding the design process. Mamluk architects strategically used specific geometric mechanisms, not only to generate ideas, but also to guide further design decisions and to express their design organization, either explicitly or implicitly.

From the compositional perspective, the distinctive design of the madrasa cleverly combined the use of common geometric shapes with geometric principles such as symmetry, similarity and transformation, rotation, reflection and scaling to generate geometric composition. The common geometric features of composition in madrasa composition can be extracted as follows:

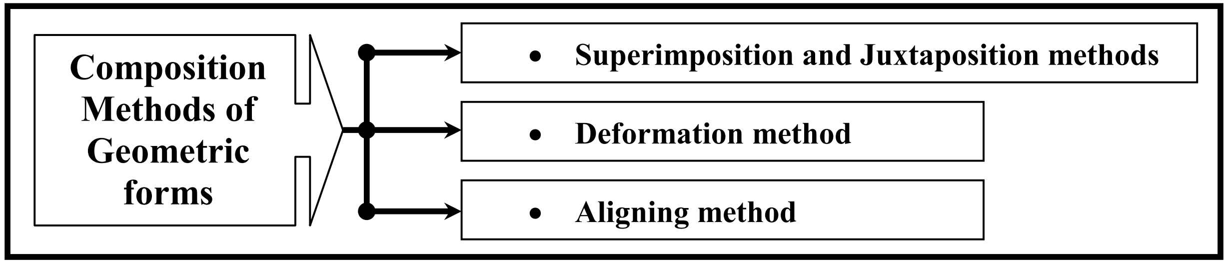
- Most of the Mamluk madrasas were erected on restricted sites. The exterior layouts of these madrasas respected the shape of the site they were constructed on. Thus, irregular ground floor plan shapes were almost always generated. However, considerable thought and effort were often put in by the designer to make the building regular in shape inside, by using basic shapes as the basis for generating all interior spaces forms. Most of the major interior spaces were oriented toward the "qibla direction" (Makkah direction), and this led to the appearance of intermediate spaces between the perfectly regular shapes of the interior spaces and the irregular outer boundary of the site [Eilouti and Al-Jokhadar,2007]p.11.

- The common geometric feature of the overall madrasa plan was a square courtyard with an almost square iwan in the centre of each side, and along the intermediate walls the living cells of students were arranged. The design components besides the huge interior courtyards and the great teaching stone vaulting iwans include mausoleums under high cupolas, residential cells and minarets.
- Later Mamluk madrasas tended to rise vertically in a number of stories, as opposed to the flat horizontal expansion of the early ones, which provided space for the multitudes on the same ground level. In addition, they tended to attach subsidiary units such as tomb chambers and sabil-kuttab to the main madrasa functions, converting their simple geometric forms into large funerary complexes. In the two cases the open space at the centre of the building was a key element in the success of the overall geometric composition in general and the plan in particular.
- One of the common geometric features in Mamluk architecture was the dependence of design on multiple axes. These multiple axes (either representing symmetry or alignment) used to create much more complex relationships, like grids, in order to preserve the morphological relationship between the geometric shapes and architectural elements whether they were volumes or plans.
- A popular geometrical feature of composition was the symmetry or alignment line that aligns individual design elements (whether they were rooms, windows, columns or stairs) with respect to it. Aside from the compositional order that resulted from such use, symmetry or alignment axes represented meta-elements that controlled the spatial organization of other, lower level elements. The power of the axis was a design strategy perhaps best expressed when it is used implicitly as a virtual line. This clearly suggests that the designer was not relying on the axis line as a compositional element in itself. Rather, its sole function seems to be one of regulating relationship between design elements and the meta-organizational concept of symmetry [Akin and Moustapha,2004]p.37.
- The geometric structure of the facades was derived by extending the axes of the plan. These extended axes organized the distribution of architectural elements of the facade, at the same time used to represent associations and alignments of the plan spaces independent of shape and size. As a result, the mutual geometric relationships between the plan and the facade were defined by the position of the architectural elements

3.4.1.2. Composition Methods of Geometric Forms in Madrasa Architecture

Composition is the art of arranging the visual elements within a frame in order to make it aesthetically pleasing for the viewer's eyes [Channdra]. Forms are voids or masses which define objects in space. Form implies space; indeed it cannot exist without space. In architecture, there are some basic design criteria that architects have to take into consideration when they compose the building geometric forms. These criteria are treated as architectural parameters. These parameters emerge from architectural design principles that make architectural forms functional, and integrated during the architectural design process to accommodate the practical requirements of architectural forms. They can be set as site conditions, orientation, designer intentions, human scale and other parameters concerned with the design of geometric form. As architectural forms are developed the interpretation of these parameters yield the resultant of architectural form. The Mamluk architect used three compositional methods to generate the geometric forms of madrasa; they are as shown in the following figure:

Figure 3-19: Composition methods of geometric forms in madrasa architecture



a- Superimposition and Juxtaposition Methods

In architecture, superimposition is the placement or laying of shape over an already-existing shape, usually to add to the overall form effect, but also sometimes to conceal something. The juxtaposition is the act of positioning two forms close together or placing them side by side.

Generating the geometric form from initial simple configurations is made by the method of superimposition, be it in two ways, a superimposition of element upon element, or operation upon operation. In the first case the Mamluk architect combined different elements, such as vaults, domes, columns and walls, or elements of the same family but of different sizes, in his geometric forms. The nature of this combination is such that each of these elements loses its independence, taking part in the composite whole of a very geometric character. For example, by analyzing the Madrasa buildings form it is found that it combined different spaces (services space, four iwans, and a larger courtyard within an even larger pediment) and all of them were being roofed by different elements (volutes, domes, flat roofs, etc). In the second case the Mamluk architect used combination of two basic operations in his composition, for example he applied bilateral symmetry and sequence of elements onto each other. The examination of the independent systems combinations, such as the Mamluk superimposition of axis of spaces on one side, and street axis on the other, presents that these systems never collide and they are functionally independently homogeneous and almost without exception share the same geometric system.

The use of superimposition and juxtaposition as tools of investigation in Madrasa architecture gives advantages to explore multiple geometric forms easily, and allows manifest superimposition or juxtaposition of three different geometric layers, as follows:

- The first layer is the layer of lines or axes. The centre of this linear layer is formed by two axes: the first axis is the direction to Makkah coordinate and the second axis is the perpendicular on it, which link up the four schools of the Islamic legal traditions to the madrasa. To the Mamluk architect axes no longer limit a certain domain, they no longer link up a series of meaningful sights, they are no more and no less than what they are: alternative tracks through the building.

- The second layer consists of a system of points. A grid is drawn over the whole building site. On each point, a main space will be built. This second layer of points should allocate space to what can be called point-determine activities, specific activities that take place within the concentrated space of a point.
- The third layer that is put on top of the previous two is the layer of surfaces. These surfaces provide space for all activities.

b- Deformation Method

The architectural message relies on decoding of architectural form, and to access the specific meaning (and not just the global) of architecture, it is necessary to use a differential morphological analysis. Often, morphological analysis merely describes the envelopes without highlighting structures that underlie them. This confusion between the appearance of a form and its structure has discredited this type of study, which recognizes only superficial and insignificant differences between the forms [Borie, et al.,1986]p.193. Furthermore, it is not impossible that morphological analysis can provide a fresh approach to the architectural semantics.

Deformation is a technique of adapting the forms to their context. It allows unity in architectural form by avoiding the inherent distortions in the transition process from idea to form. It is a technique that ensures the coexistence of forms, namely the architectural composition techniques. It is a phenomenon which appears in all scales and among the qualities of form. Accordingly, it reveals the complex nature of architectural design. Deformation refers primarily to problems of architectural design techniques. Thereby, it constitutes a forming or composing method, more or less conscious, and can be considered in the problem of geometric design as a possible technique for assimilation models. Deformation helps to explain some evolutionary processes of geometric forms, and without becoming a compositional method it can be applied in certain phases of architectural design.

The geometric forms are characterized by the imposition of forms of a defined system of relationships. However, organic forms are characterized by an apparent lack of geometry. The deformed shapes would appear to be transitional forms between the two previous formal system categories (geometric and organic), the geometric to the organic and sometimes reversal of the organic to the geometric [Borie, et al.,1986]p.47. In Mamluk architecture it is even possible to find a plan where the three formal systems (geometric, organic and deformed) are used simultaneously, probably in order to express or adapt the internal spaces functional differentiation.

Figure 3-20: Deformed shape fits to two geometrical order (orientation order and orthogonal order)
a- Madrasa of Sultan Hassan,
b- Mosque of Amir Azbak al-Yusufi.

The problem of madrasas is their inclusion in a given environment. There are two categories: those directly immersed in an urban fabric, and those forming part of a monumental complex. In the first category, this insertion into the urban fabric is made with or without the intermediate spaces schedules (ablutions room, latrines, and small cemetery). The case of no intermediate spaces such as Madrasa of Sultan Qalawun Fig. (3-21a) and the case of intermediate spaces such as when the building is surrounded by additional functions forming a secondary spaces, these secondary spaces are deformable without much discomfort and used to amortize the difference between the orientation axis of the building and the block that contains it. In the second category it may be a small mosque annex to a madrasa or in connection with a monumental square. In this case whenever possible, the delay axis is caught in the thick walls, for disobedience of inner and outer envelopes. At the Madrasa of Sultan Hassan (Fig. 3-20a), the overlap between the surface of the madrasa and the mosque is occurring in the thickness of the walls.

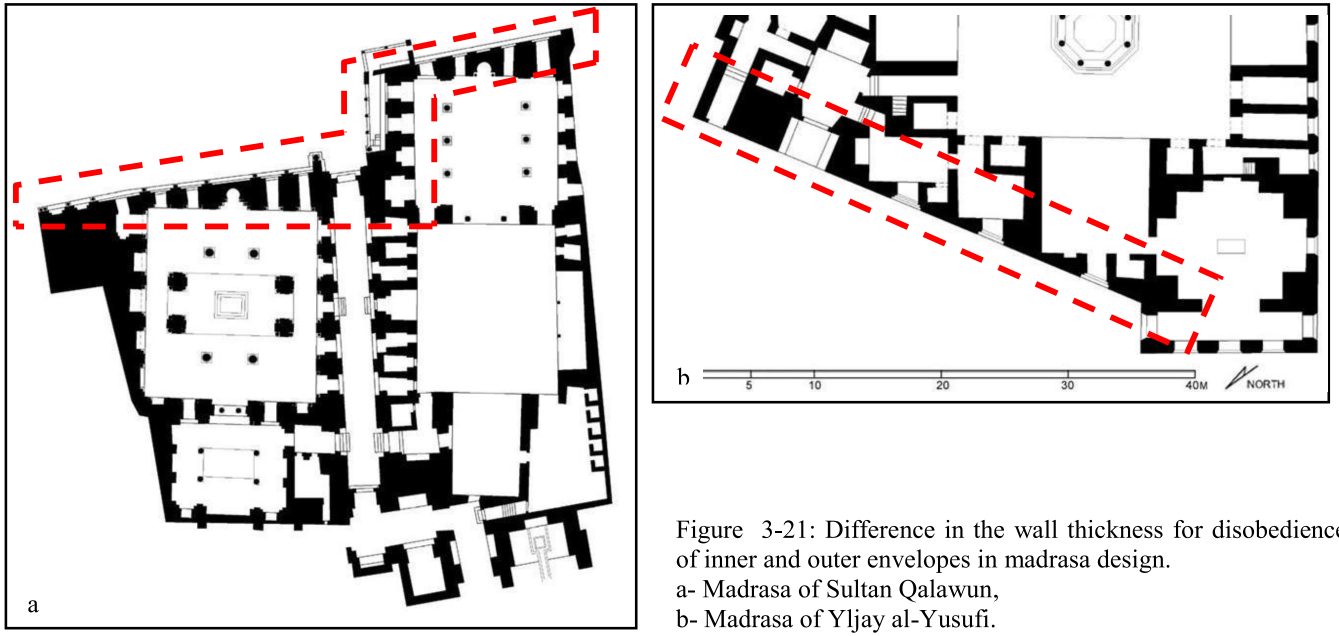


Figure 3-21: Difference in the wall thickness for disobedience of inner and outer envelopes in madrasa design.
a- Madrasa of Sultan Qalawun,
b- Madrasa of Yljay al-Yusufi.

To conclude, it can be said that the meaning of the deformation is inversely proportional to its natural appearance. Plus it poses problems for the geometric compositions on which it operates. It is rich in meaning for the same composition. It was found that the Mamluk architect who sought regular forms through all kinds of constraints, avoided or were hiding deformations in the secondary parts of buildings. This "architecture technique" helped the Mamluk architect reach the adaptation on threefold: the adaptation of geometric composition to their functions, the adaptation of geometric forms to their urban context, and the adaptation of geometric shapes to their content.

c- Aligning Method

The use of aligning method is most obvious in the plan composition and consequently the elevation and section composition, which proceeded from the plan. The Mamluk architects used aligning between forms horizontally and vertically. The horizontal aligning can be easily seen in the use of an axis as a reference to the geometric composition. The Mamluk architect could generate all the composition around it and from it. The vertical aligning can be observed on the building facades. The Madrasa buildings facades can be observed as four-storey buildings but in fact the internal space is a single-story structure.

Their structures were primarily single stories, but the use of horizontal lines and versatile volumes made their spaces seem spacious and flexible, which gives a building a more spacious feel in a smaller area. Indeed, the underlying aligning between forms is one of the aspects which drew Mamluk architects to generate geometric order in design. This geometric order consisted of primarily geometric shapes in simple forms and hidden lines of aligning. The Mamluk architect grasped forms by reaching their underlying geometry.

Geometry expressions were very much alive in Mamluk architecture, because the representation of human and other animal forms was strictly prohibited. Mathematics and geometry were the only appropriate expressions of order and perfection of form created by an architect. Thus, pure geometric shapes - circle, square, polygon, stars - and straight lines were employed in aligning compositions to produce the timeless Islamic architectural language of building design, also, the Mamluk architects favored rectangular shapes over curves and arches. In this context the use of aligning lines give the building forms, spaces, and ornament the sense of unity.

3.4.1.3. Geometric Patterns in Madrasa Architecture

The term ‘pattern’ denotes the use of a basic unit of composition which is the ‘repeat unit’. It is by the systematic application and arrangement of the repetitive unit that the pattern is produced. A single composition, however complicated, is not a pattern; but a single shape, an image, or an elaborate composition becomes a pattern if repeated regularly and systematically over a surface [El-Said,1993]p.14. One of the chief characteristic that gives the madrasa design of the Mamluk world its distinct identity is the universal application and use of geometric patterns, which leads to the belief that they were designed according to a clearly formulated method incorporating a coherent and adaptable system of composition allowing both variation and innovation. In this study it is considered that a creative part of Mamluk design exists in choosing the combination of geometric patterns to use in a particular design. These combinations of patterns are also rather like words in sentences which can be combined in an almost limitless variety of ways. Each pattern is a pre-designated element of a language and from the use of these geometric patterns in many ways of architectural solutions emerged the sophisticated creativeness of the Mamluk architect.

Mamluk architects produced geometric pattern compositions by the manipulation of regular polygons, i.e. squares and rectangles, as the design repetitive unit, and the process of constructing these repeat units involves interrelationships of various geometric forms. The repeat geometric pattern, which gives the Mamluk design its character, is determined by certain polygon (square or rectangle), repeated in design with varies sizes. The dimension of the repeat geometric polygon is achieved without necessitating the use of an arithmetical system. The graphic method used to construct the geometric composition does not necessarily require any familiarity with sophisticated and complex types of geometry. It is a practical geometry, utilized by the broadly illiterate craftsmen, as a means simply to create and reproduce geometric design.

In almost all madrasa design, geometric patterns formulating the design graphical code. Furthermore, geometric patterns made possible an ideal method of shaping areas without resorting to complicated mathematics. Even with the development of geometric shapes, in plan design or facade design, the practical application of geometric patterns is complete in itself. Mamluk architects’ designs confirm the role of geometry and geometric systems as an exact way to govern composition when measurements are not commensurable through the use of the simplest geometric patterns: square patterns or rectangle patterns, which are used respectively in the design of plan and facade. For this reason using geometric patterns is without doubt a fundamental aspect of composition and design of madrasas.

3.4.2. Spatial Design in Madrasa Architecture

Every architectural object can be considered as the spatial system. Every spatial system (or architectural object) contains a definite number of spatial elements and units of different kinds. The general definition of any spatial system based on the enumeration of its main spatial elements; the importance of the spatial elements in the spatial system depend on: its location in the system, its dimensions, and its spatial function in the system. Any spatial system can be described as follows [Niezabitowski,2009]p.95:

1) It is an ordered and cohesive set of components, creating the whole which is different from the components,
2) Every component in the system is characterized by a set of features,
3) All components are connected by a set of geometric relations, which is called the structure of the system,
4) Every component remains in specific relation to the whole system or serves particular function in it. The set of these relations (or functions) is called the organization of the system.
5) Every system as a whole remains in definite state, defined by set of features which are constant throughout the chosen period of time.
6) Some systems undergo the processes of changes, or modifications, which means (among other things) that one can make different operations on the system components.

From analyzing madrasas buildings it was founded that in the Mamluk era the building is developing a system of volumetric and the courtyard space is individualized by the architecture of its facades. The main axis coinciding with the qibla is emphasized by the proportions of the courtyard and the position of the mihrab. The subordination of the whole monument's volumetric and spatial composition to the movement along the main axis, are in evidence of the structure of the madrasa type. In them the courtyard space is connected with the many secondary, uniform cells [Notkin,1989]p.53-55 madrasa buildings, thus, tended to become architecturally self-sufficient, imposing their law on the street system rather than depending on a predetermined circulation layout.

The evolution of ideas about space during Mamluk era involved the finding of the "solidity" of the nucleus and the accentuation of the building main axis. Ideas of unified space were transformed under the influence of the multiplication of the signs of the qibla and the use of four iwans in the courtyard composition, which had already taken place in the 12th century. There was a common denominator: the courtyard occupied a central position, the iwans sprawled around the courtyard forming a religious community centres. This progress in spatial structure one ought to attribute the emphasis on compactness, the shortening of ways to reach the focal points, the integration of communicating spaces by extending structures along an axis or around a courtyard [Notkin,1989]p.55. It explains how the typology of buildings and their construction can establish the line of transmission for ideas about the organization of the volumetric layout of monuments according to their functional qualities.

Exploring spatial aspects of architectural form and laws of shaping can help one understand better not only Mamluk architecture as such, but also comprehend the Mamluk architect who creates and uses it. The following deliberations are the trial of exploration of spatial phenomena in Madrasa architecture, which should be of crucial importance for shaping the built environment of high quality. Three main aspects about the spatial design of madrasa building are presented: spatial geometric elements in Mamluk madrasa architecture, spatial rules in madrsa buildings architecture and finally, the spatial arrangement and spatial determinants in madrsa buildings architecture.

3.4.2.1. Spatial Geometric Elements in Madrasa Architecture

Designers of the madrasa buildings express in their own ways the character and unity of architecture by using local materials and applying a geometric language to generate its geometric composition, in which each spatial element is unique in its composition, according to its position in the whole. The functions of every one of these spatial elements is expressed harmoniously when it perceives a perfect dynamic relationship with surrounding interactive elements as well. The geometric composition of the madrasa can be described as a set of spatial patterns of various complexities organized one within another and all of them relate to one another formally to create a seamless continuum of complexity. The similarity of spatial patterns in madrasa compositions provided the most appropriate "illustration" of the coherent geometric order, which confirmed the intrinsic unity underlying the multiplicity and variety of manifested forms.

The building compositions have five related formal properties: number, geometry, proportion, hierarchy, and orientation [Hanlon,2009]p.3. These formal properties operate at all scales of the building design and produce spatial patterns at all scales. By examining the madrasa of Mamluk designer, its formal structure reveals a complex system of geometric compositions besides a well-designed hierarchy of space organizations and spatial patterns. Analyzing the Madrasa buildings reveal that, there are thirteen spatial elements that constitute all the composition of the madrasa. All these spatial elements are related to one another functionally to create a seamless continuum of form. These elements as shown in the following diagrams, can be determined as follows: the Courtyard (Sahn or dorqa'a); South-Eastern Iwan (Qibla Iwan); North-Western Iwan (opposite to Qibla Iwan); North-Eastern and South-Western Iwans; Entrance spaces "Dorka"; Main Entrance and portal space; Corridors; Ablution Space; Sabil (free water fountain); Tomb or Mausoleum for the Madrasa's patron; Minaret; Teacher's House (Sheikh's House); Small Cells for the Students. All these spatial vocabularies elements are founded in one building form as in the most Mamluk Madrasa buildings, or divided into two parts across the street as in the mosque and khanqah of Amir Shaykhu al-'Umari and Madrasa of Sultan al-Ghuri.

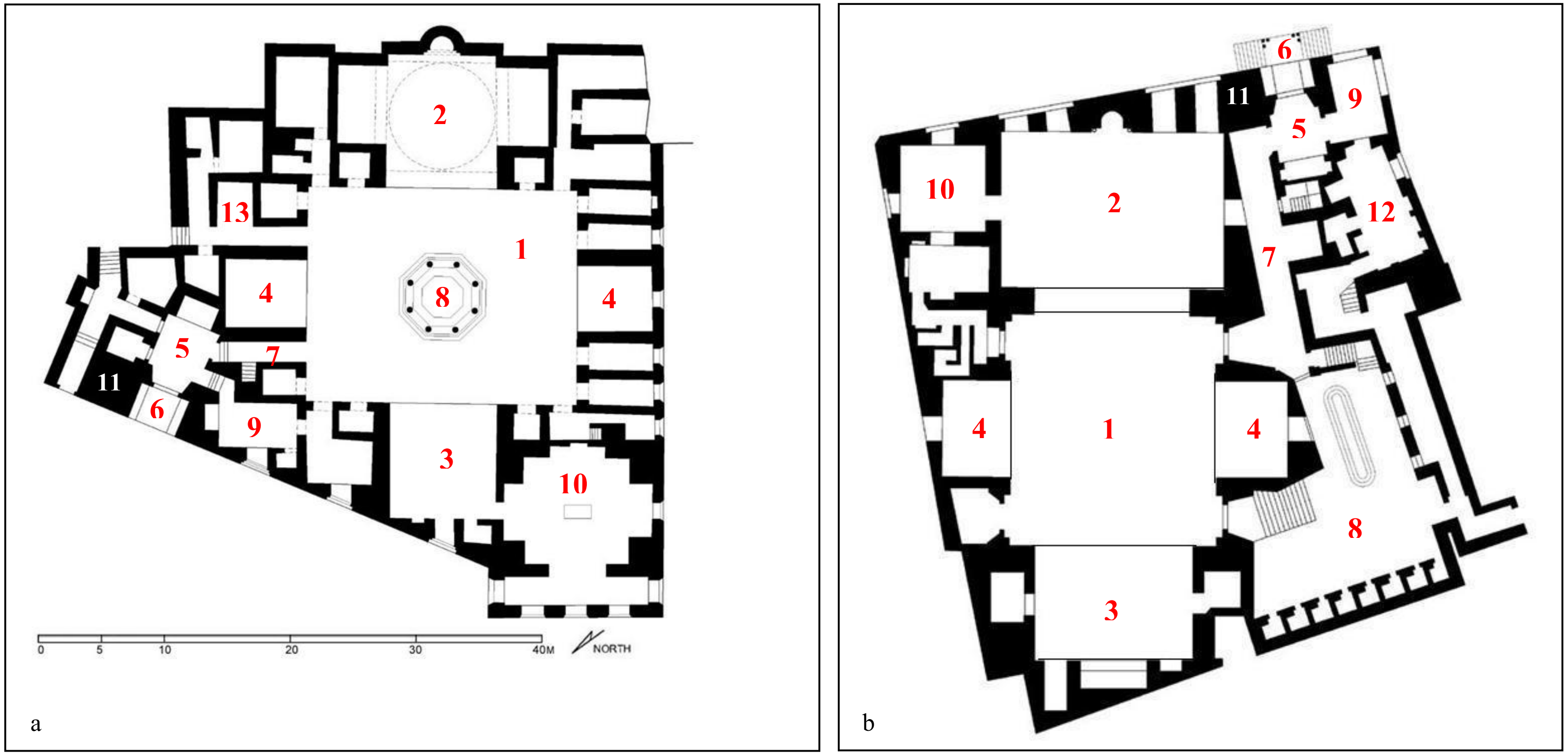


Figure 3-22: The different spatial elements in the composition of madrasas.
1-Courtyard (Sahn or dorqa'a); 2-South-Eastern Iwan (Qibla Iwan); 3-North-Western Iwan (opposite to Qibla Iwan); 4-North-Eastern and South-Western Iwans; 5-Entrance spaces "Derka"; 6-Main Entrance and portal space; 7-Corridors; 8-Ablution Space; 9-Sabil (free water fountain); 10-Tomb or Mausoleum for the madrasa's patron; 11-Minaret; 12-Teacher's House (Sheikh's House); 13-Small Cells for the Students.
a- Madrasa of Saraghitmish, b- Madrasa of Sultan Barsbay.

3.4.2.2. Spatial Rules in Madrasa Architecture

Spatial rules control the choice of the position of every architectural element in the building design. These rules are applied in specific form as a means of establishing a specific sequence of operations that could represent stages of design. They can be classified in general into two types of rules;

1- **Orientation rules**: orientation rules are a kind of spatial rules which control the orientation of the building spaces, according to the Qibla orientation or the street alignment orientation, they are as follows:-

d- The building main spaces oriented to Makkah.

e- The building' outside facade in almost madrasas suit the street alignment. To solve the orientation contradiction between the building spaces orientation and the street orientation Mamluk architect introduced the urban wall or moving the building to back leaving an approach space in front of the building.

2- **Positioning rules**: positioning rules are a kind of spatial rules which control the positioning of different spaces inside the building form. There are many positioning rules that control the spatial distribution of the spatial elements in the geometric design of madrasa buildings in Mamluk architecture. They can be summarized as follows:

- The religious buildings are shielded off from the main streams of public life. The madrasas, often closely knit together or built wall to wall in the case of courtyard structures form inward-oriented autonomous units which are protected against visual intrusion from the street or from neighboring buildings. The access from the public areas to madrasa building is usually tortuous and broken into successive hierarchical sections which herald increasing degrees of privacy.
- The main entrance, the mausoleum and the qibla iwan are facing clearly the main street. (this rule functions only if the building orientation did not come into contrast with the qibla orientation, because sometimes the building site was not oriented in the qibla direction so the qibla iwan will be in the back of the building but the main entrance and the mausoleum still face the main street, as shown in Fig. (3-23a,b).
- The four iwans surround the open courtyard, while other spaces are located on the sides and mainly in the first floor.
- The minaret is always in a closed spatial relationship with the main entrance, so its location is above or beside the entrance.
- In addition to each iwan, many facilities have been located. These include a residential unit for the teacher (Sheikh), small units for students and small courts.
- The ablution and water closets are located in the back of the building for ventilation, and oriented to face the sun, and their level is lower than that of the building itself.
- The kuttab is attached to the sabil (free water fountain) and they are always located on the building main facade, and in precisely in the corner of the building.
- A surprise encounter with the courtyard was one of the Mamluk architect's favorite ideas. Narrow stairways, narrow passages and small gates leading to the courtyard of the madrasa were architectural designs which had already been tried in early Mamluk madrasa. In each of these designs the sudden appearance of the courtyard in front of a visitor comes as an element of surprise. Walking through the building makes the visitor aware of the symmetrical order on which these complexes are based. The visitor can perceive this phenomenon spatially, but cannot experience it visually.

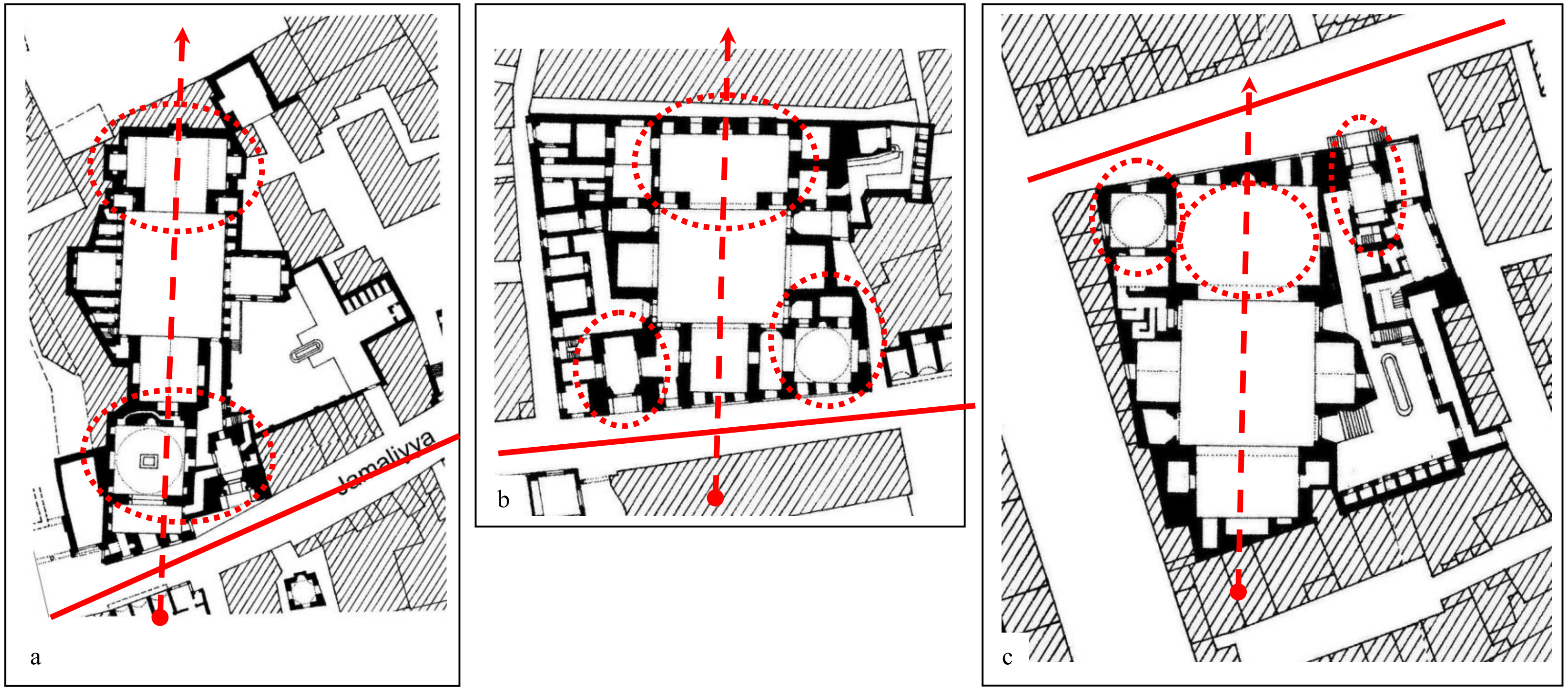


Figure 3-23: The effect of the orientation to Makkah on the spatial relation between the street and the main entrance, the mausoleum and the qibla iwan.. a- Khanqah Baybars al Jashnakir, b- Madrasa of Yljay al-Yusufi, c- Madrasa of Sultan Barsbay.

3.4.2.3. Spatial Arrangement and Spatial Determinants in Madrsa Architecture

The form of the traditional buildings is determined by several socio-cultural factors which could be considered as primary forces, whereas physical aspects are mostly generators of variants and could be considered as changing factors. The form of a building could hardly be understood outside of its the environment, the culture or the way of life of the society where it is built [Aboukhater,2008]p.110. The Mamluk madrasa is a building type that is found almost all over the Mamluk region. It is considered as a cultural heritage building and one of the meaningful examples of Mamluk architecture. Most forms of madrasa present certain similarities in their spatial arrangements through different periods, which are due to similar functional requirements, with little variations from one country to another.

According to the spatial arrangements of the spatial elements inside the madrasa buildings there are three types of movement structure that could be identified in Mamluk madrasa: linear, looped and fan shaped movement. Every one of them is determined according to the kind of user and his demands. These types of users circulations help in understanding the main characteristics and spatial properties of madrasa building that correspond to some users' needs and in respect with the way the madrasa is used.

1- Linear Structure Movement

- this structure of the user's movement results from the linear sequence of spatial elements in the building form.
- The progression inside the madrasas follows a linear disposition (Figure 3-24). There is sequential relationship from the street (from outside to inside and from public to private or semi-private). The private spaces are normally at the end of the line or at the upper floors which permits privacy and less interaction with other spaces.
- Mamluk architects tried to achieve two benefits by using this kind of movement structure. The first is the transition control of movement between spaces, and the second is solving some climatic problems which are related to the high temperature, following the obligation to pass from one space to another gradually, with a temperature that is higher or lower while entering or exiting.

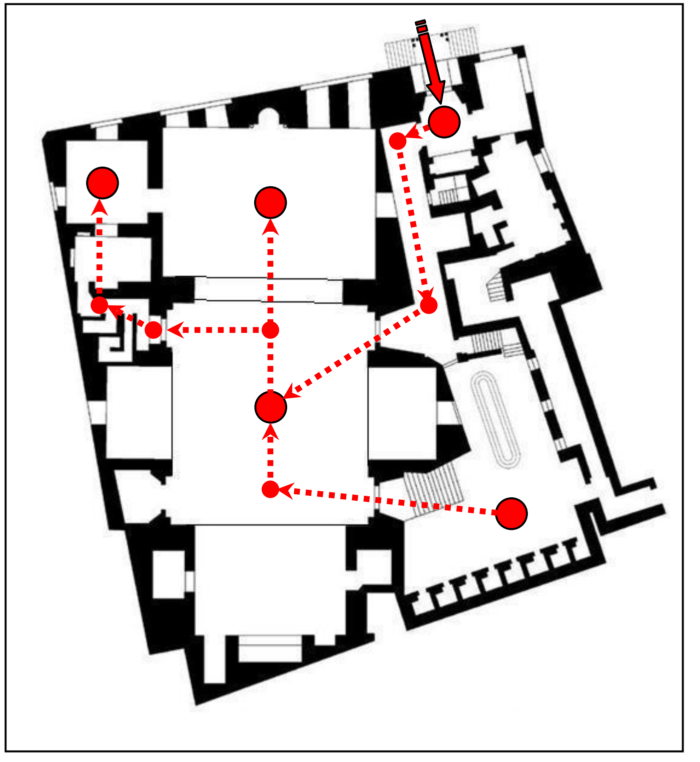


Figure 3-24: Linear structure movement in Madrasa of Sultan Barsbay

2- Looped Structure Movement

- This structure of users' movements results from the connection of spatial elements in a network with multiple choices of pathways for the users. The result is many possible pathways which permit diverse encounters.
- Ring or looped structure exists in many madrasa (Figure 3-25). In this case there is no control which is contradictory with the essential principle of the madrasa based on safety control and the gradual transition of users between spaces.

3- Branching Structure Movement

- Fan shaped or branching structure (tree) permits control access to a range of spaces from a single space. It is found precisely in the internal courtyard area in the complex madrasa forms (Figure 3-26), Any user can go from the courtyard to any other space inside the building. This structure is not dominated generally by any person's control.

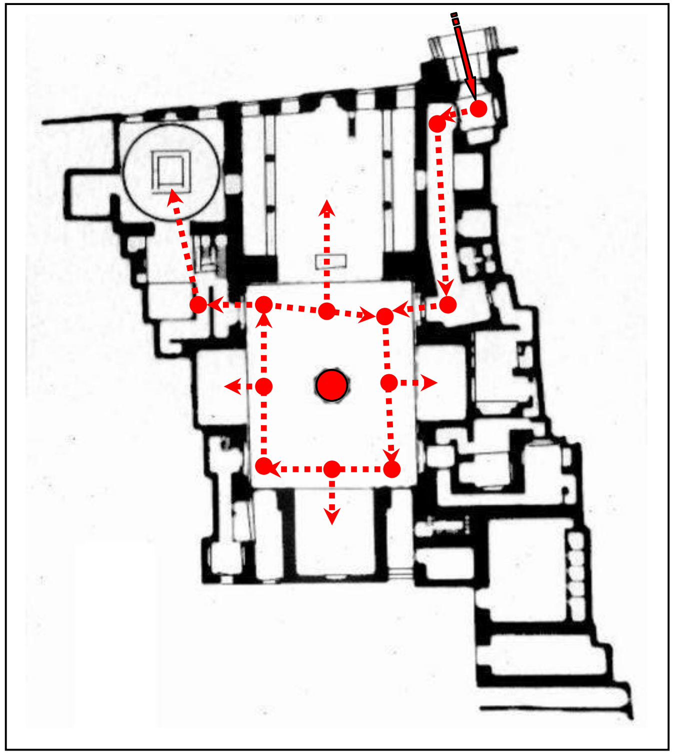


Figure 3-26: Looped structure movements in Madrasa of Sultan Barquq

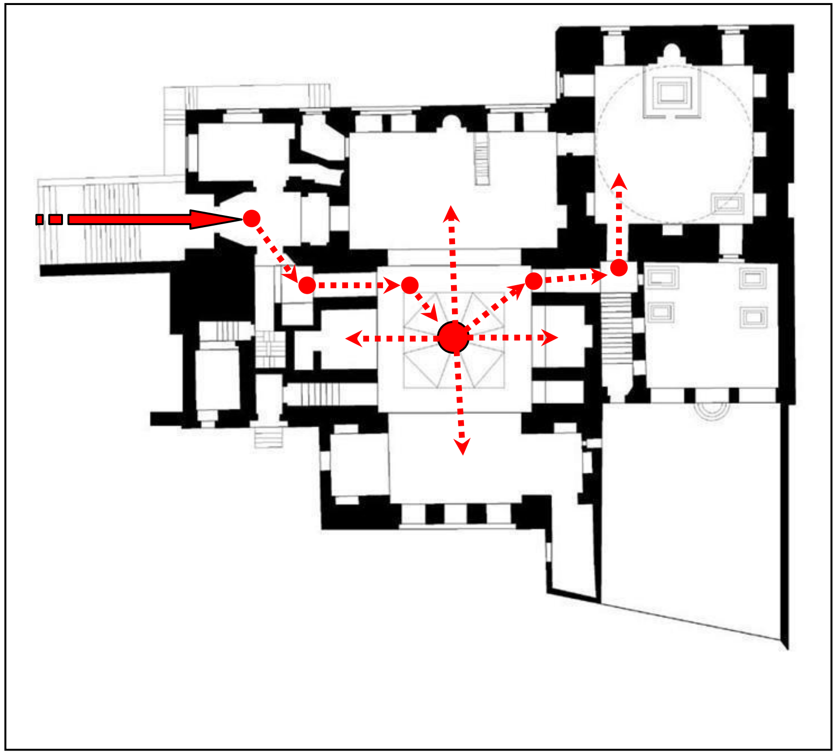


Figure 3-25: Branching structure movement in Madrasa of Sultan Qaytbay

The following figures identify the type of movement structure that could be found in the madrasa. These functional relationship diagrams demonstrate the distribution and the spatial arrangements of the spatial elements inside the building form, indicating how the outside and inside merge without overlapping and forming layers of spatial definitions, and explaining why after the exterior door of the madrasa the entrance space is usually indirect and has an L shape, or a wall in front of the door is built to protect inside the madrasa from "outside eyes" beside guaranteeing the silence which is recommended for praying. These functional relationship diagrams also demonstrate that all of these different functions are sharing spatial proximity through the creation of a specific spatial order. This order reveals a hierarchy of centrality, which is the main factor influencing the designer's spatial arrangements decision-making.

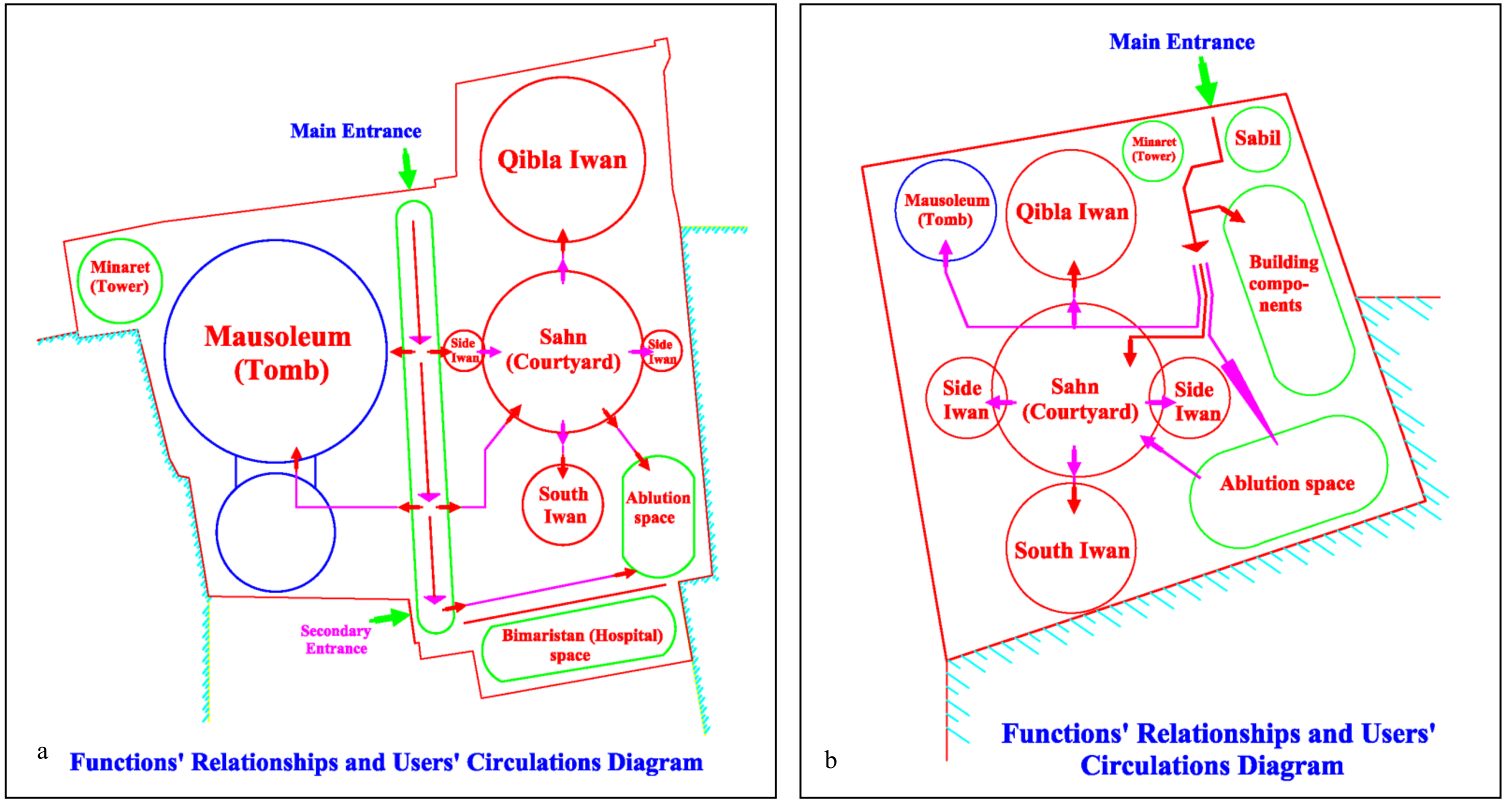


Figure 3-27: Functions' relations diagram in Madrasa buildings
a- Madrasa of Sultan Qalawun, b- Madrasa of Sultan Ashraf Barsbay

Spatial determinants in madrasa building can be the building urban context or the building site circumstances. These two factors affect the arrangements of the spatial elements inside the building form. For example, in some building sites the designer or architect is forced to divide the building into two parts across the street, so the distribution of the spatial elements inside the final form composition of the building, in this case, comes under the effect of the site circumstances.

The madrasa spatial design had been studied through the determination of the spatial geometric elements and the studying of the movement and interrelation between spaces, visibility inside the building, and demonstrating the spatial arrangements of the inner spaces that constitute the whole building, and studying the spatial elements directivity and the spatial rules control that and determining the cardinal feature which defines dominating directions of spreading the component in the building form. This helps to understand how the Mamluk architect could generate the three-dimensional form and in the following chapter this aids the suggestion of a generative technique for three-dimensional spaces design in madrasa buildings.

3.5. Design by Using Geometry

The main significance of the madrasa and Mamluk religious buildings lay in their external forms and ensure visual recognition of their architectural construction as monuments. Geometry was the language of Madrasa architecture, which made possible the diverse stylistic developments of exteriors not only to indicate a function but also to evoke a geometric response. This was achieved by the organization of building spaces in definite positions by using specific geometric rules to form the whole structure's form.

In this section the research traces the use of geometric schemes back to the very earliest methods used in architecture for designing of space. In fact, in the absence of exact tools and units of measurement, it was possible to transpose a plan from one site to another by reference to a geometric systematic method inscribed within an 'inherent geometric scheme' of variable cases. The geometric scheme which has served as the outline for the original plan would be superimposed upon it and inherent in it to be the hidden code of the design. The important thing from an aesthetic point of view is the qualitative and non-quantitative nature of such a procedure in which the implicit presence of the inherent geometric scheme guarantees a harmonious relation between the parts and the whole. Once the framework had been laid down (the main axis would be traced out by means of a compass and cord on the site of the proposed building and the position of the main functions, as entrance position, determined according to the building site urban circumstances), the architects and builders could place the various spaces of the design in hand within it, giving free reign to their imagination which was thus guided but not suffocated; a perfect rule inspires, it does not deaden. From the geometric scheme it is possible to generate a madrasa design suitable for any site, once the building boundaries are determined. The main axis is located and the main spaces' centre points are determined. The geometric method enabled the Mamluk architects or builders to create freely yet easily and correctly without the restrictions of a numerical system. Perfect inter-relationships between the parts and the whole of the composition were attained irrespective of mode, form or scale of expression.

Clues from a traditional design technique in current use can be observed to explain how this organization of space could have been achieved. In the construction of geometric patterns, in some traditional Islamic crafts, the compasses and ruler are the only two major instruments used. In principle, this method is reminiscent of the rope-stretching techniques of surveying, using peg and rope for a pair of compasses in the planning of buildings in Ancient Egypt. One has found, through the utilization of geometry (meaning literally land measure), a perfect method to shape areas without resorting to complicated mathematical calculations, such that after the development of mathematics (the decimal system), this method, remained unaltered [El-Said and Parman,1976]p.3. Mamluk architects must have developed a reproducible method, by using compass and cord, to trace oriented straight lines on the building site. This enabled them to establish a geometric procedure for generating precise and accurate constructions of a particular style, such as the madrasa buildings in Cairo. They depended on these two instruments in the process of laying out the building's design on site. They used a geometric scheme as a guide line to generate its design and also depended upon it during the process of laying out the building. The systematic geometric scheme in its design plays the role of the secret code by which the design can be understood and transferred to any other building site at any place and at any time during the Mamluk era.

Architectural design is basically the geometric organization of spaces. From the previous debate it is obvious that there is a geometric scheme inherent in madrasa design. In order to explain that four main points are presented. The first point is demonstrating how the Mamluk architect used geometry in madrasa design; the second point is explaining his geometric methodology of composition; the third point is the tools which the Mamluk architect depended on constructing that geometric scheme in the building site, and finally, presenting his methods for geometric design in madrasa architecture.

3.5.1. How the Mamluk Architect Used Geometry in Madrasa Design

It is difficult to write with certainty about the use of geometry in madrasa design and construction in Islam prior to the Ottoman period. This is, principally, due to two factors. First, the knowledge that was available had disappeared because it relied on the traditional process of oral transmission, and second, documentation of Islamic buildings is much poorer than one might expect. Although buildings were admired, architecture was seldom written about. The architects themselves did not leave any record of the work they produced. Drawings, estimates and accounts, if they ever existed, have not been passed down to us. These difficulties are moderated by people's ability to extrapolate backwards in time in certain areas where building design has changed less than in most, and by searching for clues hidden in the surviving evidence.

Design and construction – separate processes in today's architecture – were inextricably interconnected in Mamluk architecture. Through describing the construction process it will be easy to understand how the Mamluk architects used geometry in the building's design. The construction process in the Mamluk era can be divided into two steps. In the first step the buildings were laid out full scale on site, normally with ropes and compass. In the second step as the building rose, the details of the elevation were calculated such as the positions of the windows' openings and the inscribed lines from the floors.

Using Islamic beliefs as his mentor and geometry as his tool Mamluk architect developed what is called religious architecture. He used geometric principles as a formative idea and geometric shapes as keys to the consistent and systematic quality underlying all designs of madrasas. To the Mamluk architects the geometric diagrams and the geometric relations between the geometric patterns were ways to reveal timeless way of design and for him geometric solution became a resource for great intellectual and spiritual insight beside that it became for him a correct way to reach much of design aims. We will present some of these aims and explain how he depended on geometry as a main tool to reach them in design at all or at least on the stage of suggesting the design idea. These aims can be summarized as follows:

1- The role of the geometric system in his design is to create a set of visual relationships between all the different parts of the building, and between the parts and the whole, to provide a sense of order in the overall structure.
2- The application of the geometric principles in his architectural design enables the overall structure of the building to be integrated, from the site to the smallest detail.
3- By using geometric principles he tried to find a common shared geometric way of design that links and connects the architectural-spatial elements together in the building form.
4- The constructive geometry of the Mamluk masons "did not require mathematical reasoning to move through the geometric process". The problems which seemed to require mathematical calculations were solved through the construction and manipulation of simple geometric figures, using basic working tools.
5- He tried to visualize the potential architectural forms within certain geometric figures.

For the Mamluk architect the architectural composition is a process of forming geometric relations between spaces axis and spaces centre points to achieve the design aims. The design began by laying out inter-related spaces' centre points' position, and then shapes are constructed by delineating underlying and intersecting spaces axis, as design progress geometric concept is manipulated and changed dynamically. It proceeded with the designer adding new regulating geometric relations and shapes or changing the existing ones. In the process, many different options can be explored.

Finally, it seems that all of madrasa buildings were designed, perhaps even built, from the interior to the exterior, and because of the regularity of the interior it can be contrasted with the irregularity of the exterior. The Mamluk architect depended on geometry to generate and move in design from interior to the exterior. The existence of these geometric design principles in all parts of madrasa buildings indicates that all the building forms were generated at the stage of suggesting the design idea with these geometric principles, which have been realized through the Mamluk period.

3.5.2. Geometric Methodology of Composition in Madrasa Architecture

Methodology can be defined as the outcome of experience gained by experiments logically pursued along definite lines to achieve definite results, which are therefore replicable [El-Said,1993]p.113, Understanding the methodology of composition in madrasa architecture does not pretend to reveal all the secrets of the design process but tries to establish a deeper insight into the geometric rules of composition as applied in the architecture of Mamluk culture. The better understanding of Mamluk geometric methodology of composition in madrasa architecture, perhaps, enables people to learn that "true architect's creativity is not identical with disregard for rules and principles, but entails a mastery of them and an ability to use them accurately"

To understand the fundamental philosophy of composition in madrasa design the composition principles and design values which formulate the Mamluk architect's composition methodology will briefly presented as follows: emphasis, harmony, unity, opposition, balance, variety, repetition, and overlapping, and can be briefly presented as follows:

Emphasis: or "Centre of Interest." It is about dominance and influence. The Mamluk architect puts it a bit off centre and balances it with some minor themes to maintain his religious interest. In some buildings the Mamluk architect avoids emphasizing the exact spatial function, but he wants every part of the building composition to be equally interesting.
Homogeneous: in Mamluk architecture complementary functions' spaces are joined to produce a more attractive whole. The madrasa composition is complex, but everything appears to fit with everything else. The whole is better than the sum of its parts.
Unity: when nothing in the form distracts from the whole composition, the architect attains unity. Mamluk architects always used unity with diversity because unity without variation can be uninteresting. The unity principle of composition has generally more to offer in architecture and has a powerful effect.
Opposition: Mamluk architects used contrasting visual concepts, such as when the building composition was divided into two parts across the street, as in Al-Ghuri complex. He had put the madrasa and attached to it the minaret on one side of the street and put the mausoleum across the street on the other side and attached to it the dome in order to offer the contrast between short and tall and to emphasize the continuous visual concept effect on the viewer, see Figure (3-1).
Balance: Balance is the consideration of visual weight and importance. It is a way to compare the right and left side of a composition.

1- **Symmetrical balance:** in it both sides are geometrically similar and almost mirrored. Because symmetrical balance often looks more stiff and formal, it is sometimes called formal balance.
2- **Asymmetrical balance:** in it both sides is geometrically similar in composition form but not mirrored. It is more casual, dynamic, and relaxed so it is often called informal balance.
3- **Radial balance:** it is very common in Mamluk architect's compositions. In it everything is arranged around a centre. The geometric centre in madrasa form is the courtyard; around it all the building components were distributed on a radial balance.

Repetition: Repetition gives motion to the geometric composition. There are many ways to repeat the geometric elements in the geometric form. This can be done by size variation of the shape or the form. The Mamluk architect took into consideration how size can affect how close or how far a geometric element can appear to be from the viewer. The Mamluk architect used repetition on all of the madrasa's composition with some variations in order to avoid it being boring. However, repetition with variation can be both interesting and comfortably familiar.
Overlapping: Overlapping is often used by Mamluk architects to solve the problems of user's different circulations inside the complex buildings besides enriching the composition.

These principles of composition were used in the Mamluk methodology of composition to generate two main prototypes of madrasa layout shapes: the open courtyard madrasa and the closed or domed courtyard madrasa dorka type (Fig.3-31). The domed madrasas are usually smaller buildings, whilst those with an open courtyard are generally larger and have central iwans surrounded by arcades.

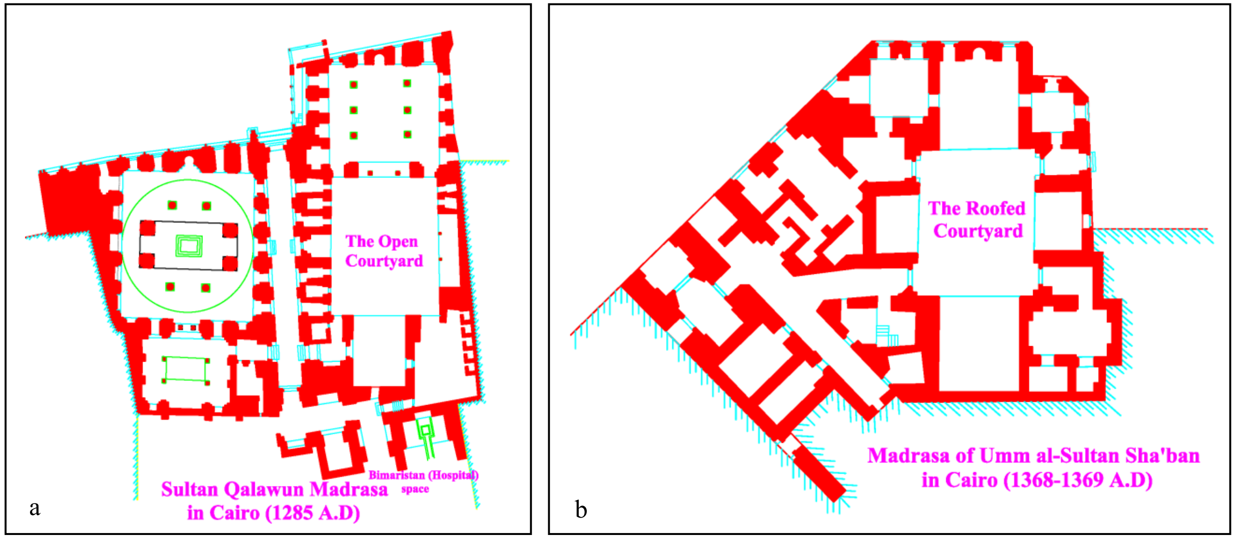


Figure 3-28: The two main prototypes of madrasa layout shapes
a- Madrasa of Sultan Qalawun),
b- Madrasa of Umm al-Sultan Sha'ban

The rules and geometric principles involved in Mamluk composition methodology ensure the accuracy, symmetry and balance of composition, thus providing a working framework for the architects and builders. However, within this framework, the architects' abilities and skills are put into effect creating the elements of composition, that is, their constituent geometric shapes and their arrangement. The lack of an apparent abstract mathematical reasoning for the practical methods of geometry, employed in the Mamluk architects composition methodology, does not imply that the composition system is without rules. It has to entail techniques and skills of ordering, measuring and calculation of a simple nature, acquired empirically through apprenticeship for the purpose of generating and executing geometric composition.

3.5.3. Mamluk Architects' Tools: Compass, Cord (Rope) and Square

The geometry, which etymologically means the object of land measure, could be considered as an essential practical tool for mensuration, its rules relying on geometric figures and numerical ratios with virtually no analytical reasoning or calculation [El-Said,1993]p.31. The geometric methods of design and construction in Madrasa architecture had started with the use of simple instruments. The compass, rope and square were the Mamluk architect's constructional tools that allowed them to make the perfect transformation of geometric shapes and figures, while guaranteeing the preservation of proportionality at the same time[2].

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[2] The earliest extant architectural treaties advocating geometry as a device for mensuration is found in De Architectura (The Ten Books on Architecture), by Vitruvius, c.30BC. See the chapter entitled "The Education of the Architect".

In contrast to the vast number of studies dealing with Mamluk art and architecture, the technology of Mamluk construction has received little attention. Much work remains to be done in this field, particularly in studying the development of equipment and tools used in Mamluk construction work. Unfortunately, no Mamluk architects or builders supplied detailed descriptions of equipment, tools, or methods of construction. In view of this absence of authoritative written sources, it is unfortunate that little use has been made of manuscripts. This is not the place for an examination of all the technical aspects involved in Mamluk draftsmanship; The research is focused only on the role of the compass, rope and square in that practice. These three tools are presented as the main tools the Mamluk architect depended on in generating and constructing his madrasa geometric composition.

3.5.3.1. The Compass

The basic instruments for constructing geometric designs were a compass and ruler [Turchinsky,2004]p.11. The Mamluk architect used the compass in his role as technical supervisor of building construction, particularly in his task of setting out the building on site. He used the compass for marking axis directly upon the site of the building. These construction lines then guided the astronomers to fix the building orientation to Makkah. They were used as guidelines by the builders who laid the foundation stones. Accordingly, the construction process was then marked out and proceeded upon these lines. With this instrument the Mamluk builder could duplicate the lines which extend in a single straight direction. This directness of method was characteristic of Mamluk building.

The history of using a compass in building design and construction in the Mamluk era faces the absence of the main treatises of architecture written by Islamic scholars themselves. There is evidence of several compendia of geometry produced during medieval times, such as those to Tabit Ibn Qura' (X century) or Al Kashi (XV century), but they seem disconnected from any practical use in the field of construction [Cipriani,2005]p.13. Their main concern lies, for example, on the definition of different geometries of arches, tracing a sequence of curves with the help of compass. Mamluk craftsmen transferred their practical knowledge from one generation to the next without leaving any documentation about their use of compass in design and construction, thus little is known about their design techniques and how they made their geometric compositions. However, their buildings' designs give a lot of information and insight. The geometric design has traditionally been done by hand and demonstrating the process of creating a composition with the same tools as traditional craftsmen have done for centuries is a good way to learn how they constructed their geometric designs depending on compass. It does not particularly require an aptitude or enthusiasm for mathematics or complex geometry; this demonstrates how the Mamluk architect could generate the spatial distribution of the building components by determining the centre points of these architectural elements depending on the compass and the straight line.

There is, however, also a field of Mamluk geometric design that is less well known. This is the tradition of three-dimensional geometric design. As with two-dimensional design, a compass and a ruler are all that is needed for 3D volumetric design. Madrasa three-dimensional geometric design can be seen as a three-dimensional version of two-dimensional geometric design.

Mamluk 3D volumetric design demonstrates the Mamluk architects' and builders' skills in using the compass and other instruments to make drawing and to set out the work on building sites. Constructing madrasa buildings with the aid of a compass emphasizes the strict geometric character of Mamluk buildings. In madrasa drawing, thirteen architectural elements determine the location of the different functions (see Fig.3-22). What is apparent at a first glance is the location of the centres of the geometric shape. The drawing is a sketch which illustrates the main locations of architectural elements and would still require other drawings to determine precisely the type of geometric schemes that would be necessary to complete the construction[3].

3.5.3.2. The Cord (Rope) and the Square

The Mamluk architect used the rope in laying out the position of the basis and walls but the square used in checking the building internal spaces and outer edges angles. In using such means in the Mamluk era to set out large buildings, the mason had to take great care to prevent mistakes. It is still hard to conceive how they could have erected all of these buildings and structures with such a high level of perfection and precision, using only primitive and naive tools. With these primitive tools they could make schematic drawings, plans and cross-sections for their buildings and fine structures that still astound the world.

From several indications it seems that the masons planned the building casing. If the madrasa building spaces were merely trimmed to fit each other as the building went on, there would be no need to have so carefully marked the place of each space in this particular way. It shows that they were probably planned and fitted together on the ground, and though it might be thought that it could be of no consequence in what order they were placed, yet all their details were evidently schemed before they were delivered into the builders' hands. The madrasa builders had a series of primitive construction aids to help them: steel square, wooden template, and string lines, but the basic features of the Mamluk builders' compass, cord and square were that of simplicity. The conclusion presses upon us that it was not the sophistication of the tools themselves, but rather the skill and ingenuity displayed in the use of those tools that made possible the great achievements of the Mamluk architects and builders.

Geometric design is a process whereby all the varied geometric steps required to lay out a design following certain rules, namely, that more than one geometric operation must be used; they should not be geometrically irreconcilable. This is a technique designed to authenticate the steps employed in the geometry. This technique could have been used for land surveying, vault projections and for determining heights. This connection between the design and construction, undoubtedly, was one of the significant success factors for Mamluk architects, perhaps the best examples come from the madrasa buildings, where the use of compass can be seen both in suggesting the building' design and in the actual process of building' construction.

3.5.4. Mamluk Architects Geometric Design Method

Mamluk architects insisted that their whole craft was based on the "art and science of geometry." It has been the purpose of this research to reconstruct the character and content of the geometric knowledge of Mamluk architects from the buildings which

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[3] This is an opening for future studies and investigation about the types of construction drawing (if it exists) in Mamluk architecture in different types of Mamluk buildings.

remain from that era. The Mamluk architects treatise on practical geometry scarcely resembles the classical geometry of Euclid and Archimedes. Mathematically speaking, once it is recognized that there was virtually no classical-geometry-type reasoning involved in Mamluk design, the way is cleared for understanding the kind of geometric thinking which the Mamluk architects did employ.

This non-mathematical technique was labeled constructive geometry, to indicate the Mamluk architects' concern with the construction and manipulation of geometric forms. It becomes evident that the "art of geometry" for Mamluk architects meant the ability to perceive design and building problems in terms of a few basic geometric figures which could be manipulated through a series of carefully prescribed steps to produce the points, lines and plans needed for the solution of the problems. Since these problems ranged across the entire spectrum of the work of the masons – proportion, architectural design and drawings – the search by modern scholars for the geometric canons of Mamluk architecture is appropriate enough, so long as the kind of geometry that was actually used by the Mamluk architects is kept in mind. The nature of that geometry suggests that these canons, when recovered, will not be universal laws which will at last provide the key to Mamluk architecture; rather, they will be particular procedures used by particular master Mamluk architects and masons at particular times and places. The geometric method, applied, developed and perfected by unknown masters of the past, is no longer a device for generating new designs, but one for producing the old.

The questions which need to be answered are the following: How were the Mamluk architects able to design using geometry? What was the method they used in planning their buildings? How did they lay out their buildings at the different sites? Finding the answers to these questions enables an understanding of the underlying geometric principles of madrasa design and accordingly an understanding of the Mamluk architects' geometric design method. The answer can be given underlying the following points:

1- It can be seen that the position of the main spaces are not chosen arbitrarily but depending on definite points of intersection within the main axis. From this remark the research hypothesises that: 'The Mamluk architect's design idea was dependent on a geometric scheme inherent in design and it helped him to converter and transfers the design from drawing into reality on the building site'.
2- The inherent geometric scheme, which gives the design its character, is determined by joining lines drawn between points established by the intersection axis of the main spaces. By inscribing the centre points, a geometric method of disposition of the spaces, and, thereby, of all the centre points of the design, is achieved. The inherent geometric scheme generated on a given set of centre points illustrates how the angles can be changed to create variations on the original design. These modifications were especially useful in the distorted sites of buildings. This illustrates the practical Mamluk geometric system of mensuration which was available when arithmetical calculations were not possible.
3- Building planning in the field was referred to as spreading or unfurling the building geometric scheme, which appeared to be a reference to establishing guidelines at the building site. The architect has been pictured placing down the peg, which determines the building centre point, while the rope-stretchers with the rope attached to this peg began the building

planning, marking distances along a straight line determining the other of the building's different spaces centre points that followed with completing the spreading of the building design on site.

The following chapter demonstrates the inherent geometric scheme the Mamluk architect depended on in his madrasa design and construction. That geometric scheme plays the role of the secret agent which converts the building design from the imagination and drawing into reality.

3.6. Conclusion

This chapter has presented the geometry behind the form in madrasa buildings and shown its rules, criteria and principles which are the basis of a successful system of composition. The notions of geometry in design as discussed in this chapter have clearly shown the qualitative and quantitative understanding by the Mamluk architect and craftsman of the geometric composition methods. This chapter has also shown that the geometry of the building design is suggested by a geometric methodology. Since building geometry is also fundamental to an understanding of a modern study of Mamluk architecture, it is obvious that the voice of Mamluk geometry still echoes through the halls of architecture.

The main results can be concluded in the following points:

- Geometric organizational principles such as symmetry, hierarchy and axiality were used to create 'perfect forms'.
- Spaces and spatial elements in madrasa composition have bilateral symmetry about the building main axes, often with a strong emphasis at the central bays.
- In the Mamluk architectural composition the geometric order is one of the basic components. The geometric order evokes the feeling of homogeneity, seriousness and monumentality, aside from reviving the architectural space and giving it an individual dimension. Elimination of geometric order from an architectural composition causes illegibility.
- Madrasa design displays ingenuity by manipulating geometrically related background geometric scheme and foreground function distributions.
- The Mamluk religious buildings were primarily based on a geometric design in which mathematical calculations and measurements played a relatively insignificant role.
- The design, which required no more than a compass and a square, testifies to the use of simple geometric means to achieve elaborate constellations, and shows that the Mamluk builder had to master a system of geometry on which the entire Mamluk design process was based without necessarily being an expert mathematician, as some have assumed.
- There is a geometric system (it can be seen as an index or design booklets that functioned both as catalogues of codified forms and as repositories of construction method. The master builders were already familiarized through experience and empirical knowledge with the language of the depicted forms and this is what is suggested in the next chapter by offering the methodology of geometric order in the madrasa buildings design in the Mamluk era.
- The Mamluk architect viewed his building design as a geometric object, and he realized the importance of geometry in drawing the relationships between the building architectural components.

- There is a geometric scheme inherent in the madrasa design the Mamluk architect depended on in his design process and it controls all aspects of the madrasa design process,
  1- That geometric scheme must have been used up during the design and construction process in the Mamluk world where it appears to have played a major role in disseminating a unified courtly architectural style.
  2- That geometric scheme explains how the centre of the courtyard was identified as the generator of the design,
  3- That geometric scheme throws light not only on how complex design were generated by means of geometric system, but also on the simpler working methods employed on the construction site.
  4- That geometric scheme, therefore, provides a rare glimpse into the creative process; it testifies to a standardized, repeatable, and reasonably flexible approach to design by simple means that produced sophisticated results and allowed great scope for improvisation.
  5- That geometric scheme provides clues as to how the master builder would organize various designs on the fabric of the building.
- In Mamluk architecture the design generated from the geometric scheme unencumbered by specific measurements was meant to be proportionally adapted to the building itself and the construction site circumstances.
- The centre, the axis and the orientation, were the three basic principles regulating the Mamluk process of “form-making”, and it was claimed that it was through these principles that Mamluk religious architecture (specifically the design of madrasa buildings) became when viewed from a geometric position.

From the previous demonstration of the geometric relationship which governs the relationship between the madrasa building’s architectural components, in the next chapter a step-by-step process is used to generate a language of design and a systematic design method and in particular a geometric generative technique for Madrasa building architectural design.

Design Method

Geometry

Islamic Architecture

Research Skeleton

Introduction

The first part — The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part — The Analytical Study and the Field Study

Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A — A Computer-Aided Generator for Madrasa Buildings Design

4. Chapter Four: Towards a Geometric Methodology of Design in Islamic Architecture

4.1. Introduction

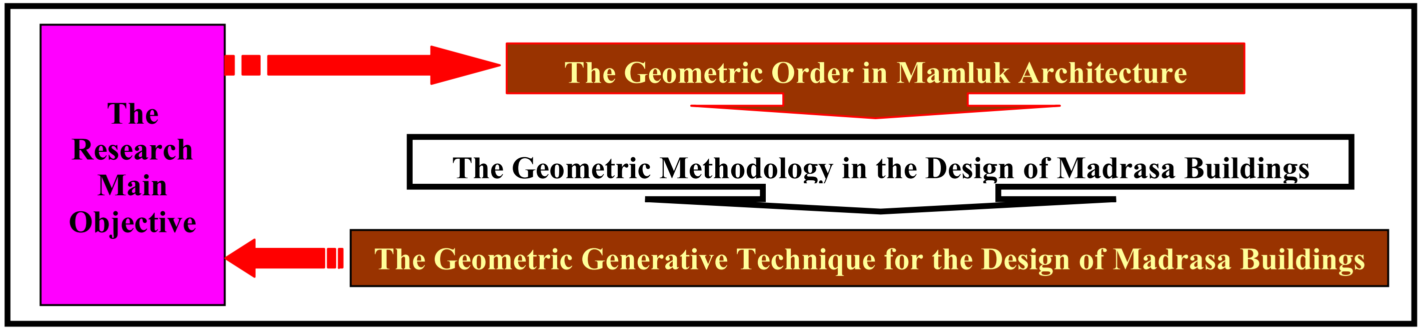
As far as it is known, no record has survived describing the theory of designing Mamluk religious buildings in general and madrasa buildings in particular[1]. In this chapter, the research attempts to illustrate how craftsmen at different times and places in the Mamluk world proceeded to apply the geometric principles to the practical problem of making the geometric concept in madrasa design. Although some have tried to describe the architecture, their work involved an incomplete or unsatisfactory explanation about the architectural design of these buildings and especially the role of geometry within it. It is assumed that these works lack the fundamental concept of what is called here the 'inherent geometrical scheme' of design. This is the systematic arrangement of the space's functions which produces the overall design.

Geometrical design is one of the most distinctive aspects of Mamluk architecture. Geometry (implicit or explicit) can be seen everywhere in the Mamluk world: on buildings, in books, on tiles, on wood, and on metal. The variety of modes of application of geometric design is endless. In the history of Islamic architecture different dynasties were responsible for major innovations in the fields of design methods. In methodologies of geometric design the Mamluk from Egypt were especially innovative. Little is known about their design techniques and how they made their geometric compositions, but their designs reveal a great deal of information and insight. Understanding the geometric methodology for the design of Madrasa buildings and how they created composition is a good way to learn how they constructed their designs.

In this chapter the geometric order in the design of madrasa buildings will be demonstrated by presenting the geometric methodology of design for madrasa buildings, which is presented by demonstrating the geometric generative technique for the design of madrasa buildings in three aspects of the building:

Firstly: the geometric generative technique for the building space design.
Secondly: the geometric generative technique for the building facade design.
Thirdly: the geometric generative technique for the building decoration design.

Figure 4-1: The research methodology for obtaining the main objective.



[1] Some historians refer that to, because it was an oral traditions, so no need to write what is lived day by day is common practice. and the transfer of knowledge was through the guild system.

The geometric generative technique is an effective tool in generating the design of madrasa building, depending on an inherent geometrical scheme, which is determined by the use of a compass and rope, and containing different angles determines the space disposition system used to generate the whole design. The choice of the Mamluk designer of one or the other of these angles affects the entire proportions and the form of his building. The research proceeds to geometrically analyze several Mamluk madrasa buildings, showing which angle was used for certain buildings (or parts of a madrasa, as the case might be). The research also provides plans and elevations of various madrasa buildings with detailed illustrations drawn all over them to show the “geometrical scheme” of the buildings and show how a compass, cord and square could have been used to set out these construction lines, some of which would have been passed through piers and walls already in existence when the new part of the building was being designed and constructed. This explains that the concept and the method with which the architects worked were the same, enabling them to achieve a totality of purpose in the architectural creation

4.2. Basis of the Geometric Methodology of Design

There are three geometrical elements that must be taken into consideration in order to understand the geometric design of the madrasa buildings. The first is the geometric shapes on which the Mamluk architect depended in his building design. The second is the axis on which he depended in order to connect the different geometrical shapes of the spaces and thirdly the geometrical angles which controlled the deviation of these axes to determine the centre points of the spaces.

In order to understand the geometric methodology of design, we will start with a presentation of the steps in which the geometrical analysis of the building can be done. Then the basis on which the suggested methodology of design depended are presented.

The following steps demonstrate how to make a geometrical analysis of the madrasa buildings:

1- Studying the urban context to determine the position of the building’s visual elements (the minaret, the entrance and the mausoleum dome) which will connect the building visually with the surrounding urban context.
2- Determining the building’s main functions which lead to determining the building’s main and sub-main spaces.
3- Determining the main space between all spaces of the building, because from this space all the building forms will be extracted, and the design process will start from this.
4- Determining the main centre points.
5- Determining the qibla direction which leads to determining the two main axes, the vertical axis in the direction of Makkah and the vertical axis which is perpendicular to the previous one.
6- Determining the building’s main axes (the axes of the different main spaces).
7- Determining the geometric shapes which suit the different functional concepts and locate them around the spaces’ centre points by the help of the spaces’ axes.
8- Joining and in-filling between the main spaces with secondary functions spaces (corridors, storages, stairs,… etc.).
9- Completing the building composition (and beginning with the construction process).

By understanding the building's geometric design it is attempted to suggest a geometric methodology, by presenting a generative technique for the design. A suggestion made for the geometric generative technique is dependent upon many bases, principles and rules. These rules control the geometrical methodology of design and they can be presented and summarized as follows:

1- The centre point of the building is the departure point of the design process
2- The design process starts from the interior proceeding to the exterior
3- The distribution of the spaces in the building comes under the effection of many factors, the most important being the religious factors, Islamic beliefs, social factors and patron demands.
4- The design of the facade depends on the organization and distribution of the ground plan.
5- Geometric principles are the secret factors which control the design process.
6- In their building design process the Mamluk architects depended on a geometrical scheme. They suggested the scheme before embarking upon the design process.
7- The geometric scheme which helps the Mamluk architect on generating Madrasa designs is like a catalogue containing the rules which differ according to the building site.
8- The design process begins with designing the building in two dimensions and then imagining the building in three dimensions. Completing the design of the three dimensions of different spaces in the different parts of the building comes during the construction process.
9- The Mamluk madrasa monuments were drawn in two-dimensional form prior to their execution.
10- The straight lines connecting the main spaces' centre points form the inherent geometrical shape in the design. This set of points is considered, during further steps of design, to be the element in question.
11- The aesthetics in architecture comes essentially from proportioning and proportioning results from geometry. The design system based on high awareness of the proportions of geometry is the key factor applied in Mamluk architecture in all their creative work.

4.3. The Geometric Order in Madrasa Building Design

The Geometric Order in building space design is shown through the presentation of the geometric generative technique for: building space design, building facade design, and building decoration design.

4.3.1. The Geometric Generative Technique for Madrasa Designs (the plan [2d design], the space [3d design])

The geometric generative technique suggested here is a technique for generating the architecture design by depending on the geometric relations which control space distribution inside the building.

A short description of the technique is presented. This is followed by a demonstration of the "language" it uses in generating the architecture design. Its main components are then introduced and finally the adopted process for generating the building architecture design is presented.

4.3.1.1. The Geometric Generative Technique Idea

The main idea of the geometric generative technique suggested here can be explained in three points:

1- The geometric generative technique in the process of generating the building design depends on determining the centre points of the main space of the building. By using certain geometric relations and by starting from the main space's centre point the designer can extract the centre points of all other spaces in the building.

2- Starting from the different centre points and by using certain geometrical rules the designer can extract the building design in 2D. These rules can be summarized as follows:

- a- Relation between a shape's axes (perpendicular, rotation)
- b- Relation between spaces (parallelism, juxtaposition).
- c- Geometric organizational principles (symmetry, hierarchy, axiality).

3- After completing the building plans in 2D and by applying the rules which govern the 3D composition of different spaces, which play the role of construction rules, the designer can convert these plans from 2D into three-dimensional spaces.

4.3.1.2. The Geometric Generative Technique Description

The geometric generative technique encourages the designer to start by studying the position of the building inside its urban context, because this is more efficient for controlling the overall architecture design. It suggests to him to take the determination of the centre points of spaces as 'The point of departure in architecture design'. It explains to him how the derivation of building design can start from organizing the interior spaces into two dimensions by using certain geometric relations, proceed in these 2D plans to the details of walls, doors, and windows, and finally it demonstrates to him how he can use certain 3D design rules to convert these plans into three-dimensional spaces.

The geometric generative technique mainly depends on two points: the Islamic principles of design, which provide the architect with the main rules by which he can generate the design of every space individually, and the hidden geometric system, which provides the designer with the angles value by which he can generate the disposition system of spaces.

4.3.1.3. The Geometric Generative Technique Language

The geometric generative technique language like any other language consists mainly of a vocabularies, rules and derivations. These derivations emerge from applying the rules on the vocabularies.

The initial shapes play the role of vocabularies (square, rectangle, triangle and circle) and the rules control the relations between these shapes and are divided into four types: rules that control arithmetic operations (addition, subtraction, multiplication, division), rules that control the relation between a shape's axes (perpendicular, rotation), rules that control the relation between spaces (parallelism, juxtaposition), and the geometric organizational principles' rules (symmetry, hierarchy, axiality). The derivations are all the architectural forms which are generated from the initial shapes by applying the previous rules to them.

<table>
<tr><td rowspan="4">Geometric Generative Technique Design Language</td><td>1- Initial Vocabularies (Shapes)</td><td>Square, Rectangle, Triangle and Circle.</td></tr>
<tr><td rowspan="2">2- Rules</td><td>1- Arithmetic operations (addition, subtraction, multiplication, division)</td></tr>
<tr><td>a- Relation between a shape's axes (perpendicular, rotation)
b- Relation between spaces (parallelism, juxtaposition)
c- Geometric organizational principles (symmetry, hierarchy, axiality)</td></tr>
<tr><td>3- Derivations</td><td>All building architecture compositions which are generated by applying the rules on the initial shapes.</td></tr>
</table>

Table 4-1: The geometric generative technique language

4.3.1.4. The Geometric Generative Technique Main Components

There are two main components of the geometric generative technique which are suggested here. The first is the basic Islamic religious design principles which provides the designer with general rules which helps him in the process of designing plans and space disposition. The second is the inherent or hidden geometric design system which plays the role of the secret factor which controls the building design and provides the designer with the values of angles by which he can determine the different spaces centre points in the building composition.

1- Basic Islamic Principles for the Design of Religious Buildings

There are many Islamic design principles for religious buildings. Those which concentrate on the role of geometry in architecture are offered here.

1- Main building spaces must take the qibla direction (Makkah direction), see Fig. (4-2).

2- Entering any space must be in a perpendicular direction to the space (especially praying spaces).

3- The building contains a courtyard (sahn) and it may be roofed or not, see Fig. (4-3).

4- The four iwans are roofed and their height equals the building's total height, as shown in Fig. (4-4) and Fig. (4-5).

5- The qibla wall is always square shaped and is the keystone or the controlling factor (or the keyword) because the heights of all the building's other architectural elements are dependent upon it.

6- The building's architectural form expresses the geometric compositions used for its different functional purposes.

7- The functional integration alongside the geometrical integration between the geometric shapes, which are used in space composition, is one of the basic design principles

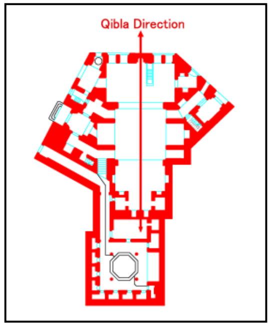


Figure 4-2: The orientation of the building main spaces to the qibla direction in Mosque of Emir Azbak al-Yusufi.

Figure 4-3: The courtyard and the iwans

Figure 4-4: The qibla iwan and the qibla wall in Madrasa of Sultan Barsbay

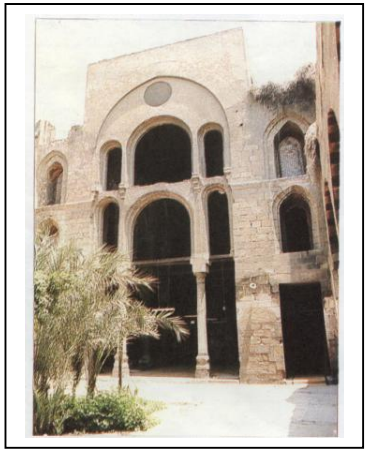


Figure 4-5: The elevation of the qibla iwan from the courtyard in Madrasa of Sultan Qalawun

8- Every one of the building spaces has its own design principles:

A- Entrance design principles :-

There are many principles for designing the entrance to religious buildings in Mamluk architecture as follows:

* The shape form of the entrance is constant and consists of the portal space which is the approach space, followed by the main space of the entrance which mostly contains two doors. One of them is on the right and the other is on the left and the solid wall is in front, as shown in Fig. (4-6).

* The entrance axis is perpendicular to the street, Fig (4-7).

* The entrance is always on the right side of the site boundary.

* In some cases the entrance is not directly alongside the edge of the site boundary with there being a distance between the entrance and the end of the site that contains the sabil, as shown in Fig. (4-8).

* The entrance spaces are roofed and their height equals the building's total height, as shown in Fig. (4-9).

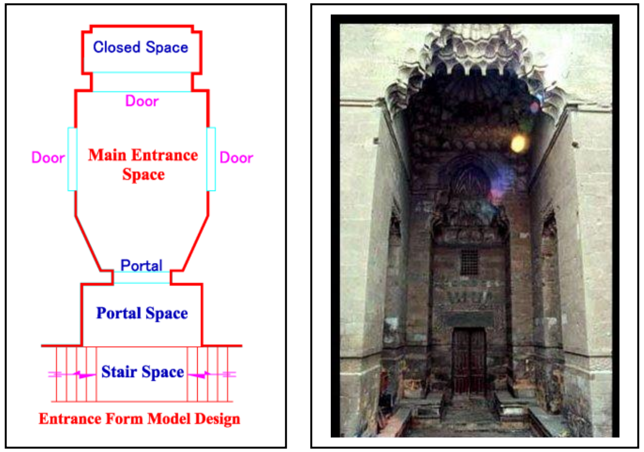


Figure 4-6: The entrance model design

Figure 4-7: The Entrance axis perpendicular to the street in Madrasa of Emir Uljay al-Usufi

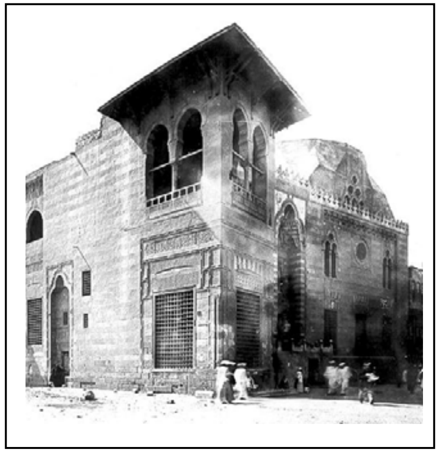


Figure 4-8: The sabil is beside the entrance in Madrasa of Sultan al-Ghuri

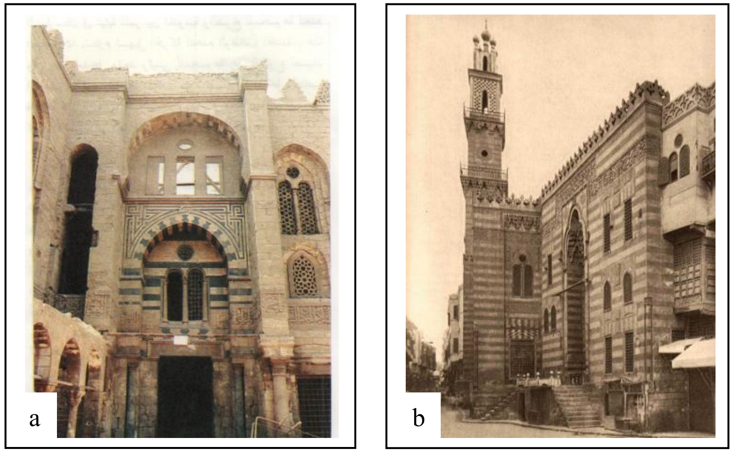


Figure 4-9: The Height of the Entrance panel equal to the building total height
a- Madrasa of Sultan Qalawun, b- Madrasa of Sultan al-Ghuri

B- <u>Mausoleum (Tomb) design principles</u>:

* The mausoleum space is divided into two spaces: the main space for the mausoleum itself and the second is the approach space.
* The approach space is the connection point between the Mausoleum space and the other spaces in the building, Fig. (4-10).
* The mausoleum is covered with a dome and its dimensions are determined according to the building's dimensions, as shown in Fig. (4-11,12,13).

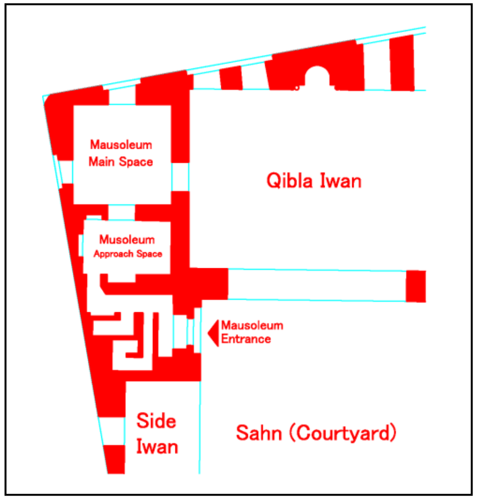


Figure 4-10: The mausoleum form design

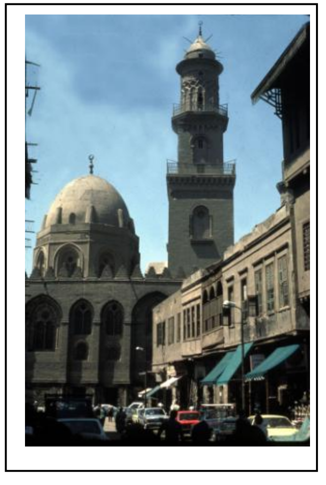


Figure 4-11: The dome above the mausoleum in Madrasa of Sultan Qalawun

Figure 4-12: The mausoleum dome in Madrasa of Sultan Hassan

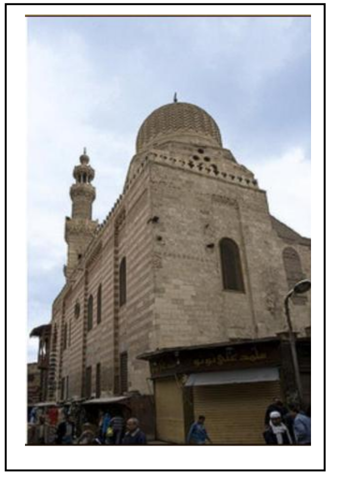


Figure 4-13: The mausoleum dome is a landmark for the street in Madrasa of Emir Uljay al-Usufi

C- Door area design principles:

Every door inside the madrasa building must have its own approach through the shoulders which are attached directly to the door wall.

D- The qibla iwan design principles:

The qibla iwan is the main praying hall within the madrasa building and contains the qibla wall, the minbar and the mihrab; it has two main design principles, as follow:
1- According to Islamic teachings it is better for there to be no doors in the qibla wall.
2- The qibla iwan must contain two entrances one from the sahn and the second is from the side cells, as shown in Fig. (4-14).

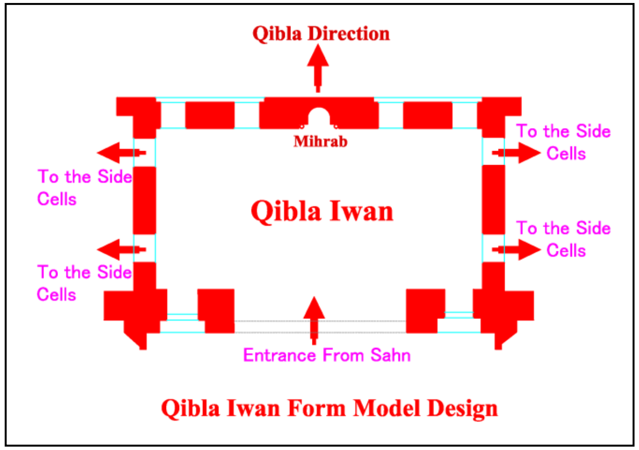


Figure 4-14: The qibla iwan design form

E- The courtyard (sahn) design principles:

The courtyard inside the madrasa building is a connective and a collective space. It connects the four iwans and collects people from all parts of the building. In some cases a fountain is placed in the centre of the courtyard. The courtyard has many doors on every side, as shown in Fig. (4-15).

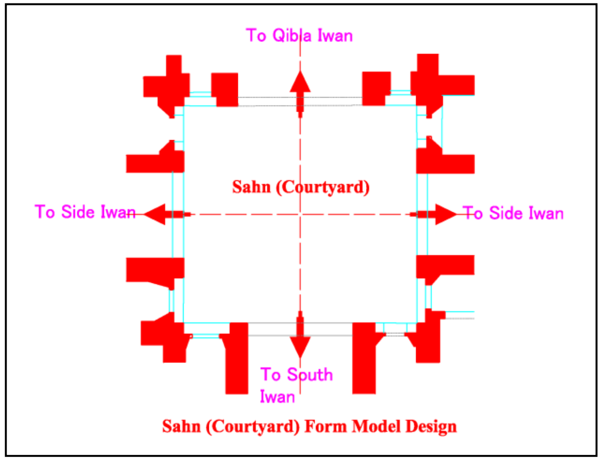


Figure 4-15: The sahn (courtyard) design form

2- The Hidden (Inherent) Geometric Design System

According to the position of the sahn's centre point and the direction to Makkah (qibla direction) the designer can determine the primary position of the four iwans (the qibla iwan, the two side iwans and the south iwan[2] which is in confrontation with the qibla iwan), as shown in Fig. (4-16).

According to the building site's urban context and by studying the visual image of the building layout, which emerges from the visual relations between the building and the surroundings, the designer can determine the position of the building entrances.

According to the position of the horizontal axis of the sahn and the horizontal axis of the qibla iwan, the entrance position can be one of the following three cases, as shown in Fig. (4-17):

Case 1: the entrance position is under the horizontal axis of the sahn centre.

Case 2: the entrance position is between the sahn centre horizontal axis and the qibla iwan centre horizontal axis.

Case 3: the entrance position is above the horizontal axis of the qibla iwan.

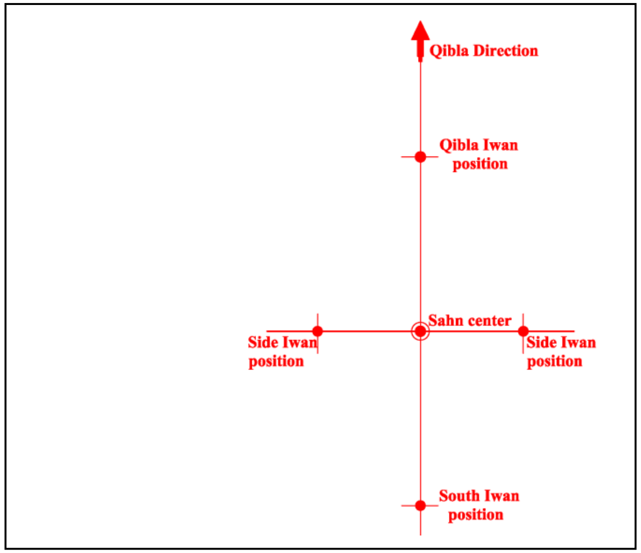


Figure 4-16: The position of the four iwans according to the position of the sahn.

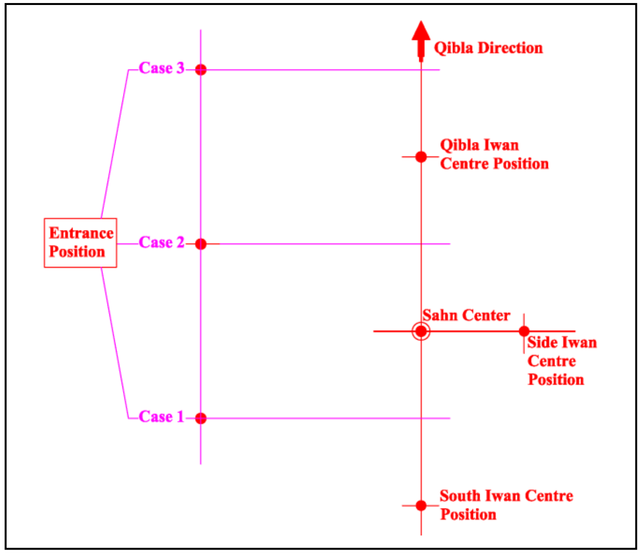


Figure 4-17: The position of the entrance according to the position of the sahn's center point and the qibla iwan's center point.

[2] We will refer to the iwan which come opposite to the qibla iwan by "the south iwan" and this is not mean or indicate its orientation to the south, but we just want to discriminate between it and the qibla iwan, because geometrically they are placed on the same axis.

1- Determining the Qibla Iwan Centre Point: (μ angle)

The designer can determine the centre point of the qibla iwan by drawing an inclined line from the entrance point and deviate from the line which connects the sahn's centre point and the entrance point with a specific angle **μ**. Its value is different according to the position of the building entrance, as follows:

In entrance position **case 1** the **μ1** value equals 10 degrees or 20 degrees, as shown in Fig. (4-18)

In entrance position **case 2** the **μ2** value equals 30 degrees or 60 degrees, as shown in Fig. (4-19)

In entrance position **case 3** the **μ3** value equals 20 degrees or 30 degrees, as shown in Fig. (4-20)

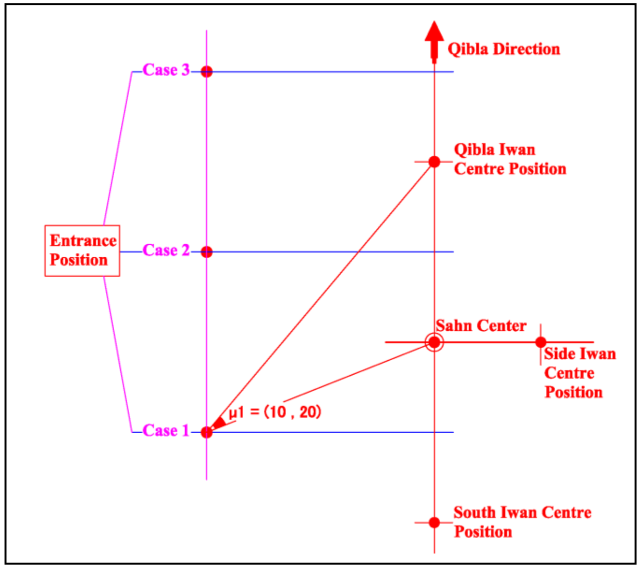


Figure 4-18: μ1 value in entrance position case 1

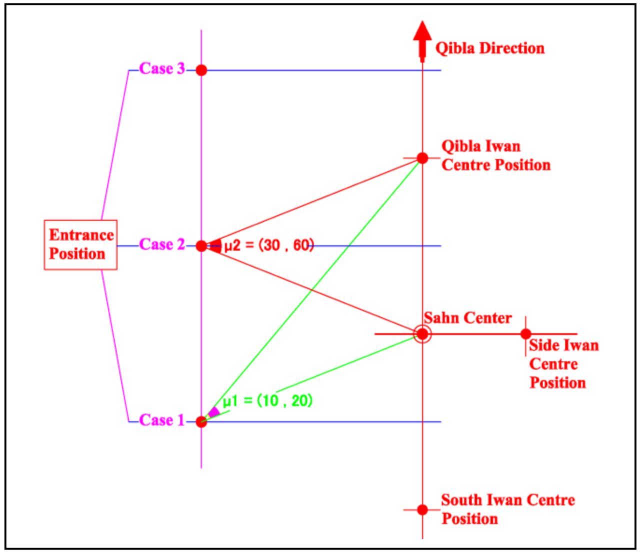


Figure 4-19: μ2 value in entrance position case 2

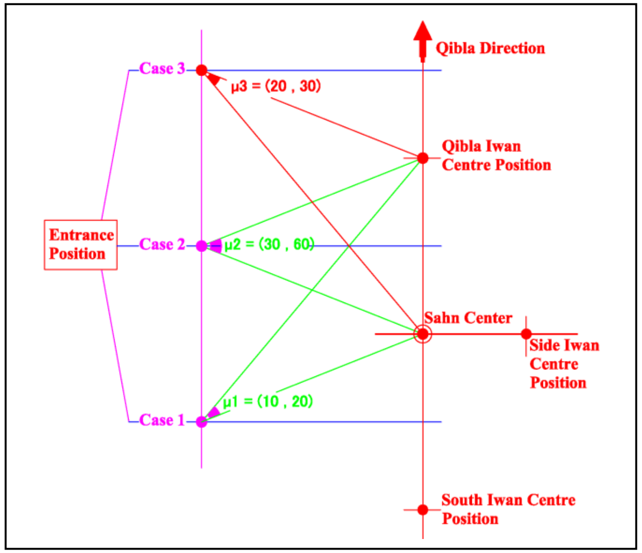


Figure 4-20: μ3 value in entrance position case 3

2- Determining the Side Iwan Centre Point :- (@ angle)

The designer can determine the centre point of the side iwan by drawing an inclined line from where the centre point of the qibla iwan intersects the horizontal axis of the sahn centre determining the position of the side iwan centre point. This with a specific angle **@**; its value is different according to the position of the building entrance as follows:
<u>In entrance position **case 1**</u> the **@1** value equals 20 degrees or 40 degrees (@1 equals $\mu 1$ or $2(\mu 1)$), as in Fig. (4-1)
<u>In entrance position **case 2**</u> the **@2** value equals 30 degrees or 60 degrees (@1 equals $\mu 2$ or $0.5(\mu 2)$, as in Fig. (4-2)
<u>In entrance position **case 3**</u> the **@3** value equals 20 degrees or 30 degrees (@1 equals $\mu 3$), as in Fig. (4-23)

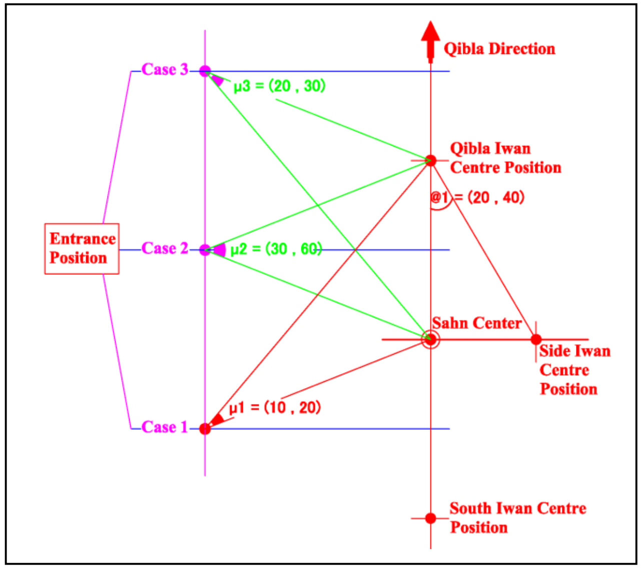


Figure 4-21: @1 value in entrance position case 1

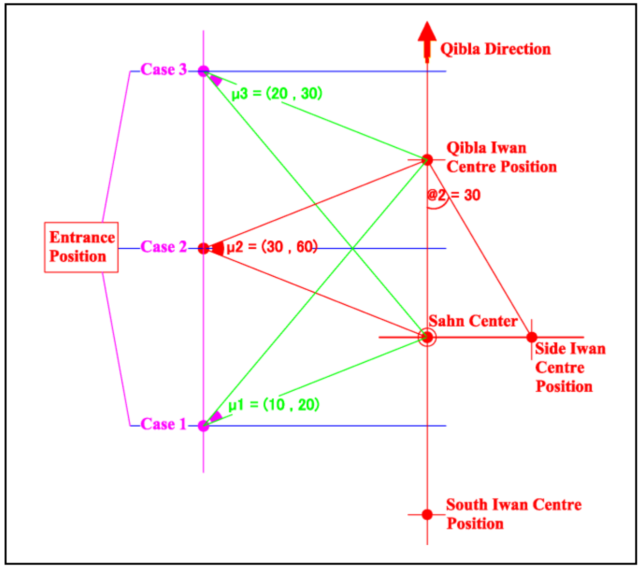


Figure 4-22: @2 value in entrance position case 2

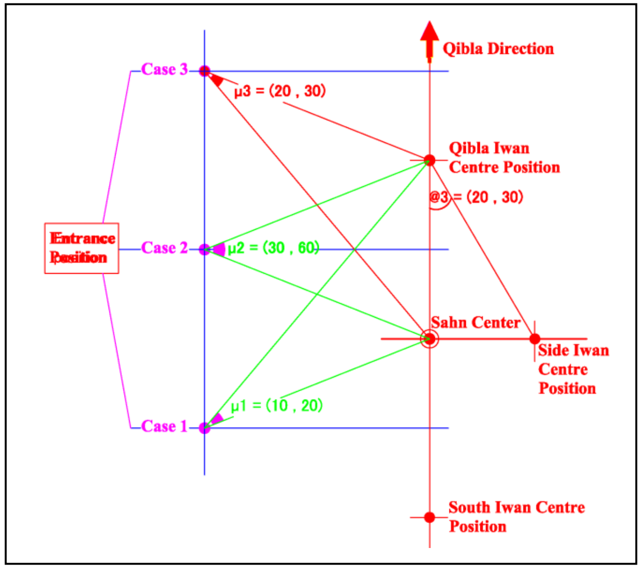


Figure 4-23: @3 value in entrance position case 3

3- Determining the South Iwan Centre Point: (ß angle)

It is known that the sum of the interior angles of a triangle equal 180 degrees. The previous angle **(@** angle) is doubled, and the resulting value subtracted from 180 degrees to get the angle **ß**, by which the line connecting the side iwan centre point and the south iwan centre point deviates from the line connecting the side iwan centre point and qibla iwan centre point, as in fig (4-24).
The final shape of the hidden geometric system is attained, as shown in Fig. (4-25).

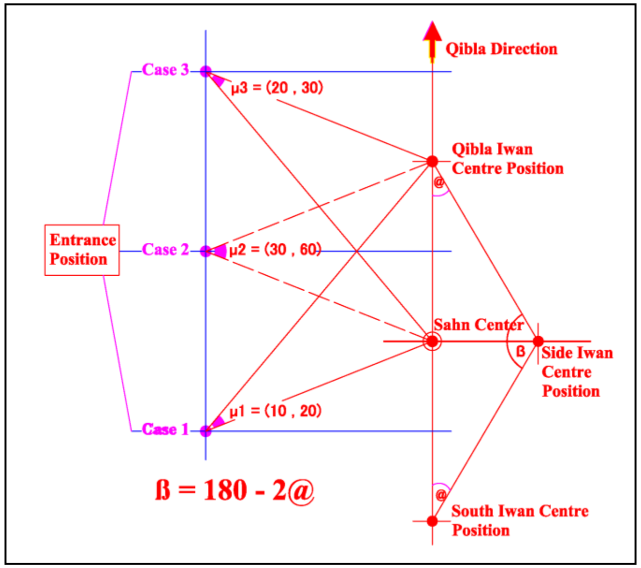


Figure 4-24: Determining the south iwan's centre point

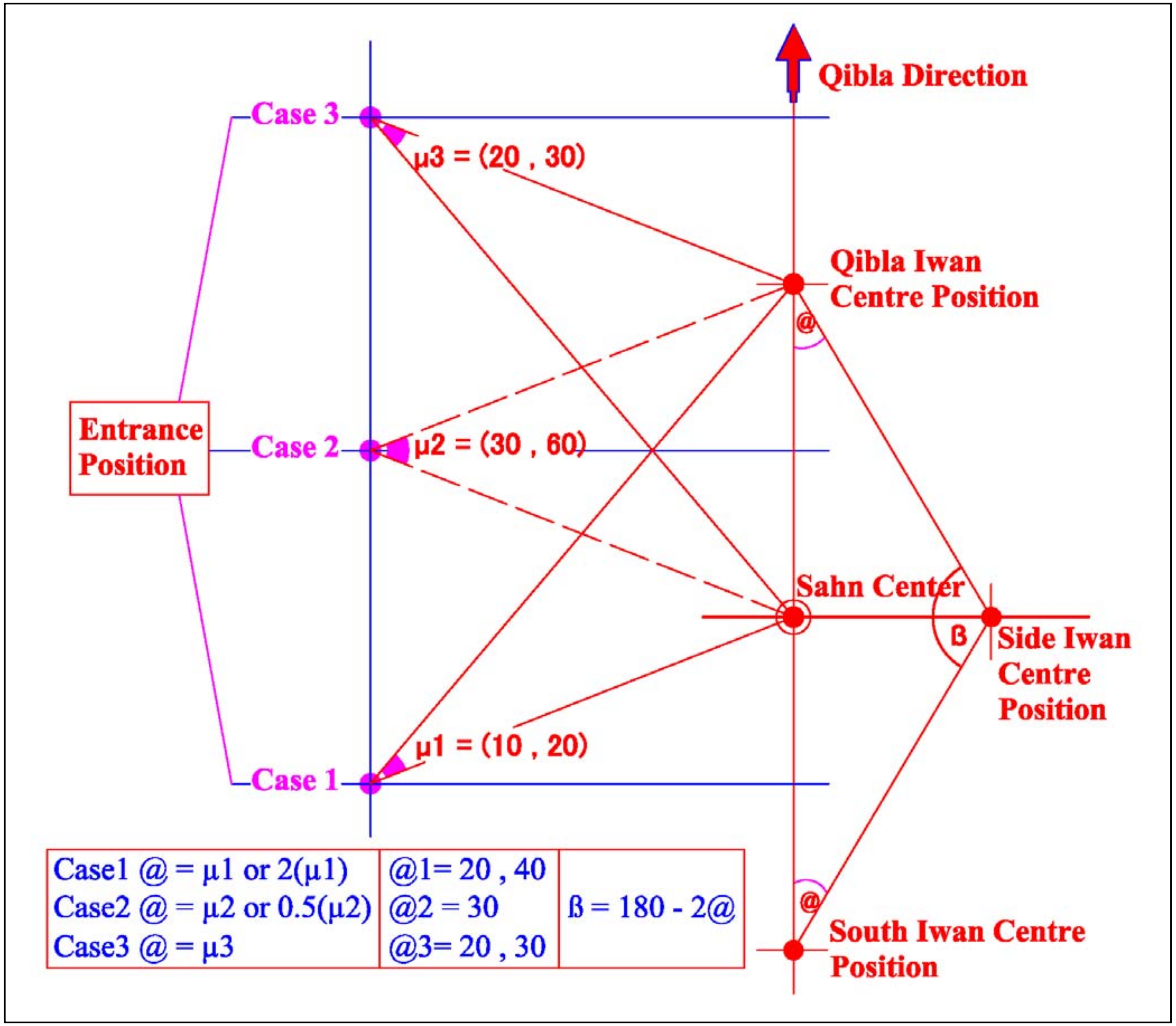


Figure 4-25: The final shape of the hidden geometric design system

4.3.1.5. The Geometric Generative Technique Steps

The Geometric Generative Technique consists of a set of Steps and every step consists of a set of Rules that control a set of Procedures. Every step provides the designer with a result, which helps him reach the next stage in the architecture design process.

<u>Pre-design step :- The building mass composition design.</u>

In this step the designer begins by studying the urban context of the building site. Secondly, he studies how the building will fit into its urban context in order to reach a unity in the visual design and avoid any conflict between the building and the surrounding urban context. He can reach this by drawing of a dialogue between the building and its urban surroundings, and this will be done by studying the place of the entrance, the minaret and the tomb dome in the building, because these three elements are responsible for the connection of the building with the surrounding urban context. Thirdly, he determines the general factors affecting the building design (for example, patron demands, the religious symbolism and the meanings which the designer wants to present… etc.). Finally, the designer ends this step by offering a suggestion for the building mass composition design, as shown in Fig. (4-26).

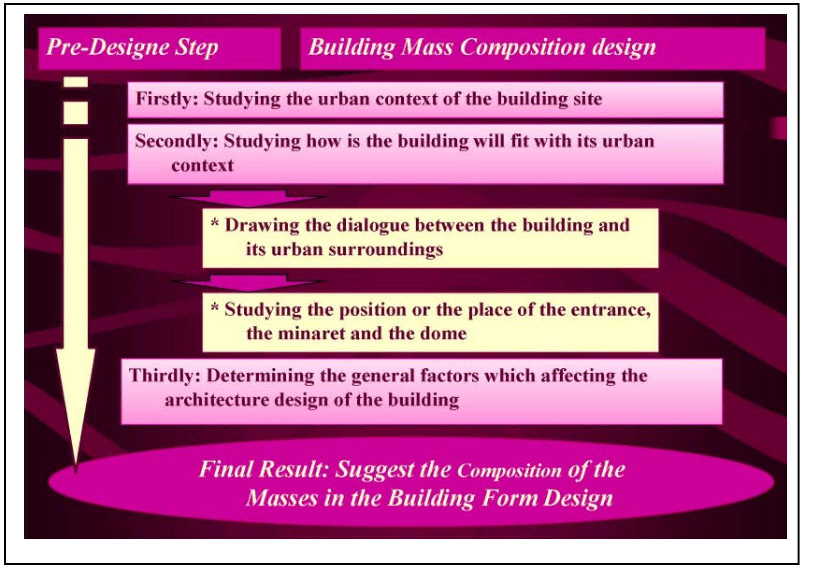


Figure 4-26: The pre-design step

<u>1- First Step:</u> Determining the site boundary, the qibla direction, and the sahn's centre point

In this step the designer determines the building site boundary and according to the qibla direction he can determine the sahn's centre point, as follows:

1 - Determining the outer limits of the building site (the external borders of the site).
2 - Determining the qibla axis direction (Makkah direction).
3 - Determining the sahn's centre point position:
    The designer determines the sahn's centre point by drawing two perpendicular lines on the site edge from the centre of the street facades or the two main facades and the intersection of these two axes is the sahn's centre point position.

4 – Determining the entrance point:

According to the study of the building's surrounding urban context, the designer can determine the position of the entrance and by using the entrance design principles he can position the entrance axes and the intersection between the entrance axis and the site boundary determines the entrance point position.

As a result of this step the designer has two known and fixed points. The first is the sahn's centre point and the second is the entrance point. From these two points he can extract all the building space's centre points. Therefore, these two points are the departure points in extracting the building composition and the architecture design.

<u>2- Second Step:</u> Determining the functions' relationships and the users' circulations diagram

In this step the designer determines two important things:

1- Firstly, he determines the relationships between the different functions inside the building.

2- Secondly, he determines the users' circulations diagram by drawing the users' walking paths or the circulation paths from the entrance. The user is directed inward to the sahn, the ablution space, the mausoleum, the qibla iwan for praying, or to any other spaces of the building's components.

As a result of this step the designer can determine the primary position of the building's different architectural components and according to them he can determine the position of the connection spaces, such as corridors and stairs.

<u>3- Third Step</u>: Applying the hidden geometric system (determining µ, @ and ß Angles)

* By applying the hidden geometric design system the designer can determine the position of four points, the qibla iwan centre point, the two side iwans centre points and the south iwan centre point.

* The designer determines them by using three different angles

<u>First angle</u>: µ angle to determine the qibla iwan centre point position.

<u>Second angle</u>: @ angle to determine the side iwan centre point position.

<u>Third angle</u>: ß angle to determine the south iwan centre point position.

The value of every angle is different according to the position case of the building entrance, as shown in figure (4-25).

<u>4- Fourth Step:</u> Generating the building plan's design (the design of the building in 2D)

In this step the designer can generate the building plans design as follows:

1- Determining the dimension of the qibla iwan:

The designer begins with the qibla iwan (prayer hall). Inside it he begins with the design of the qibla wall and then he completes the qibla iwan side cells' design.

2- Determining the dimension of the sahn, the side iwans, and the south iwan:

By using the similarities rules and taking into account the boundaries of the site the designer can determine the dimensions of the sahn and the rest of the iwans' form.

3- Designing the building entrances:

In the light of the entrance design principles, the designer can put the entrance design and determine its form in this stage.

4- Determining the location of the minaret and designing the mausoleum:

According to the position of the entrance, the designer determines the position of the minaret and according to it he can determine the position of mausoleum and in the light of the mausoleum design principles he can determine the mausoleum form design.

5- Completing the building plans:

After designing the sahn, the iwans, the minaret and the mausoleum the designer can complete the building plans by adding the remaining elements of the building's components and he can also generate the other floors, (for example, determining the location of the ablution space, the teacher's room (Sheikh's house), students' cells, the kuttab, etc.).

<u>5- Fifth Step:</u> Applying the interior space design rules

The interior space design rules are a very important factor for the designer due to the following reasons:

1- They are the secret factor which helps the designer convert the plans from two dimensions to three dimensions. They explain to him the height of every space inside the building, demonstrate to him the height of which space inside the building is equal to the building's total height and which one will be divided into two levels or more.

2- They are a very important factor affecting the designer's thinking during the design process. For example, it makes him think how to solve the problem of putting different spaces with different functions and different heights all together inside the building. They show him the importance of the degree of relation between different functions and between different users' circulations.

3- They show the designer how he can govern the construction process, because they demonstrate the relation between the different levels inside the building.

The result from applying the interior space design rules, mentioned above, the designer can determine the following:

a- The dimensions of the qibla wall.

b- The building's total height, especially the height of the four iwans, the entrance and the sahn.

c- The position of the vertical connection architectural elements (stairs, ramps).

d- The size of the mausoleum dome.

<u>6- Sixth Step:</u> Generating the building spaces disposition (designing the building in 3D).

* In this step the designer converts the building 2D plans to three dimension spaces. This means he generates the building composition by studying the relations between spaces in three dimensions, while depending on the interior space design rules.

As a result of this step: The building components are arranged in the construction process, as follows: -

1- Constructing the qibla wall	6- Constructing the minaret.
2- Completing the qibla iwan.	7- Constructing the mausoleum.
3- Constructing the entrance and its spaces.	8- Constructing the sabil.
4- Constructing the side iwans.	9- Completing the rest of the building components (ablution space, students cell,...etc).
5- Constructing the south iwan.	10- Roofing the building.

The following figure demonstrates the final shape of the geometric generative technique for the madrasa buildings space design in Mamluk architecture in Egypt.

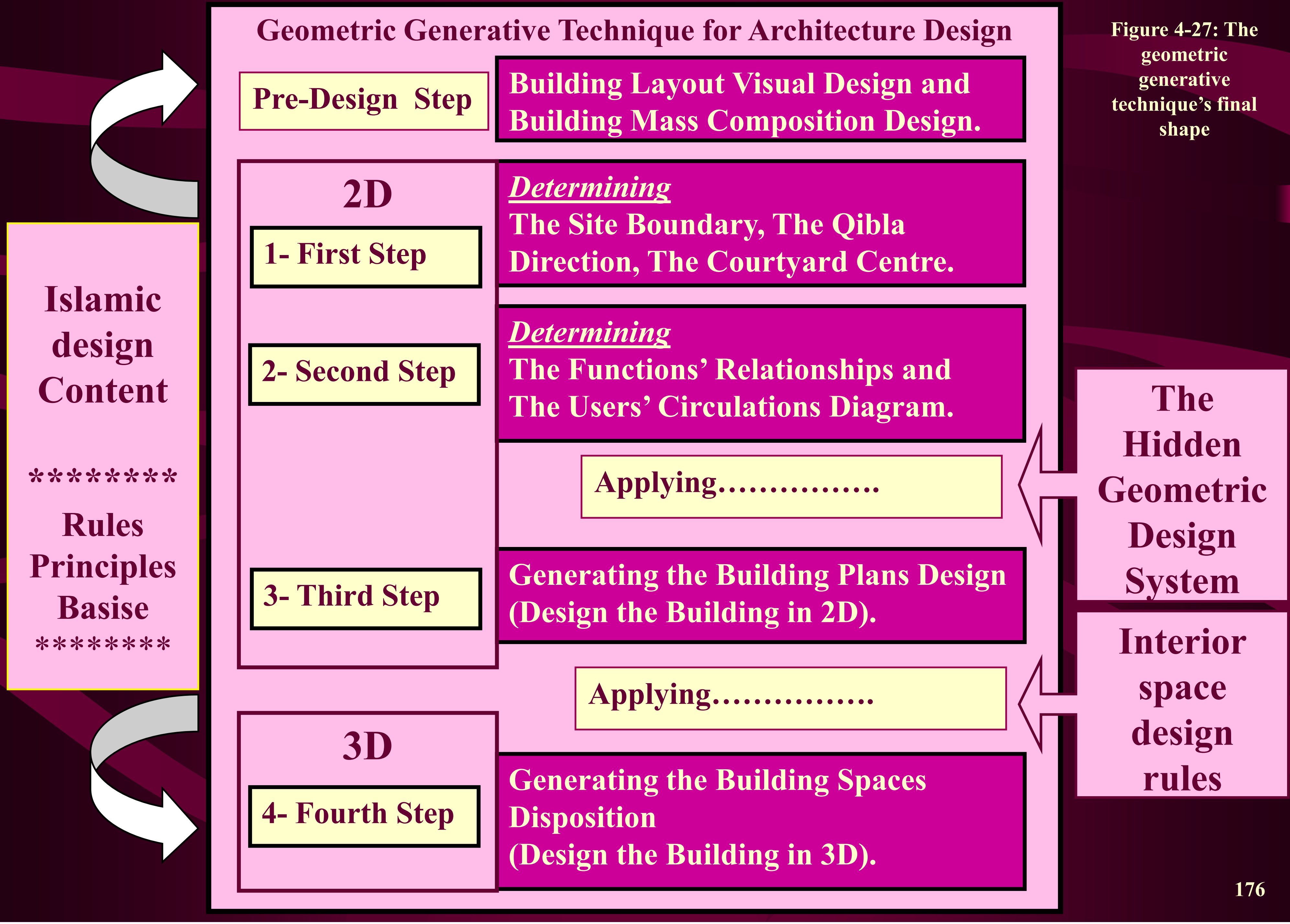


Figure 4-27: The geometric generative technique's final shape

4.3.2. The Geometric Generative Technique for the Facade Design of Madrasa Building

The geometric order in madrasa building facade design is demonstrated by presenting the geometric generative technique for facade design, which consists of several steps, leading the designer to generate the facade design, depending on a step-by-step system to reach the final design, considering the urban context's effect on the facade design. This technique depends mainly on some rules and principles which the early Mamluk architect used for the design of the building's facade.

The methodology for generating the facade design in Mamluk architecture is similar to the methodology of plan design. This methodology begins with determining the facade's outside limits or its boundary and then designing the inside facade details, such as window openings and facade decoration to complete the design. This is the same methodology he used in designing the plan, starting from the building's outside boundary and moving on to the inside details to complete the design.

The methodology for generating the facade design in Mamluk architecture consists of two main parts:

The first: Rules and principles for facade design in Mamluk architecture.

The second: The geometric generative technique's steps for generating facade design

4.3.2.1. Rules and Principles for Facade Design in Mamluk Architecture

The early Mamluk architect used many rules and principles for the design of madrasa building facades, so that an observer is able to see the high degree of similarity between all madrasa buildings which were constructed during the Mamluk era and in many different places in Egypt, Palestine and Syria. This similarity is the main reason which introduced the Mamluk style to the world. In the early 20th century some European architects claimed that this Mamluk style is the national style of Egypt.

The rules and principles of facade design in Mamluk architecture can be summarized as follows:

Rule 1: Considering the mutual relationship between the building and its urban context is one of the most important design criteria of the building; through the consistency between the building facade design and the facade design of the buildings in urban fabric one can clearly observes the Mamluk style.

Rule 2: The reflection of the plan on the building facades is one of the most important criteria in the design of the Mamluk facades, in other words, almost all building facades introduce a very clear expression about the building plan's functions, for example, by looking at the facade one can observe the position of the mausoleum inside the building.

Rule 3: The facade design process must be coordinated with the construction process of the building. The research hypothesis is that the Mamluk architect designed the facade during its construction, taking into account some general observations and rules which govern the design.

Rule 4: The designer relies on the square shape as a liaison between the building plan and its facade. The square plays the role of a starting point for the reflection of the plan in the facade design, and as a geometric shape it governs the process of selecting and identifying the height of the windows in the building facade.

Rule 5: The geometric relationship between the total height of windows, which ranges between 2.5 to 3.00 meters, and its width, which determined by the design of the wall in the plan, is a geometric expression of the geometric shapes, geometric angles (which determines the geometric relations between axes), and numbers which the designer used them in the design of madrasa buildings.

Rule 6: All window sills are positioned 25 cm above the floor. This can be explained for two reasons; the first reason is to provide the homogeny in the building's facade between the building's different spaces, which are of different height (one space can take the building's total height but another could be divided into two or more levels), and the second reason is to avoid disharmony in the design of the facade, which would result from the change in the levels of the windows in the different parts of the facade.

Rule 7: There are two main components of the facade: the windows and the decoration.

In some steps of designing the facade the designer added the window openings first and according to these he positioned the decoration elements (for example, the decoration elements around the window openings), but in other cases the designer added the decoration elements first and according to them he determined the size and position of the window openings (for example, the handwriting panel which is placed all over the facade and also the muqarnas on the entrance panel).

4.3.2.2. The Geometric Generative Technique Steps for Generating Facade Design

The early Mamluk architects went through the following steps when generating the madrasa building facade design:

1- Determining the facade's outer limits or the facade boundary and also determining the facade's total height.

He would then move inside the facade and study the details and the relations between its different components and design its different parts. This is the same methodology and the conceptual framework used by the Mamluk designer for the design of the building plan.

2- Adding the main vertical axes of the facade (qibla iwan axis, mausoleum axis and the entrance axis).

3- Designing the qibla wall plan, by dividing the qibla wall into three major parts (the mihrab part and two other parts, one of which is on its left and the other on its right).

4- Putting the sub-axes around the main axes, so the designer could design the windows on the right and left of the mihrab.

5- Determining the different floor levels (according to the number of stories which the building will have).

6- Designing the entrance panel and positioning the entrance door (its width and height).

7- Putting the facade decoration elements.

- The top decoration of the facade.
- The handwriting panel which is always directly above the entrance door or on the top of the facade.

8- Adding the facade's main squares, (representing the real height or the clear height of the space behind, the qibla iwan height for example).

9- Determining the windows' horizontal axes. They represent the windows sills in each of the different levels of the windows (usually not more than 25 cm above the level of the floor), which means the division of the facade into two or three levels of windows or more depending on the number of stories the building will have.

10- Identifying the height of the windows on each of the different levels of windows (usually ranging from 2.5 to 3.00 meters)

a- The height of the first-level window is usually not less than 3 meters to allow a full view of the street in order to provide a strong connection between the people in the street and those within the mosque. This also allows a high degree of light to enter the space in case the space is to be used for teaching). By knowing the width of the windows from the plan the designer can draw or construct the windows on this level.

b- Identifying the height of the second-level windows, knowing already the window sill 25 cm above the floor and in some cases the window is positioned on the handwriting panel which lies directly above the entrance door.

c- Determining the height of the third-level windows in the same way, by knowing the height of the window sill from the floor and also of the window itself.

11- Completing the facade windows by applying the previous steps to the mausoleum facade.

12- Adding the facade decoration, around every window and also on the top of every window panel.

13- Completing the facade design by adding the minaret and the mausoleum dome.

4.3.3. The Geometric Generative Technique for Madrasa Building Decoration Design

Throughout history researchers have attempted to discover the geometric order which controls Islamic decoration design. They introduced many methods to demonstrate how the decoration pattern can be generated using geometric rules and principles, which were organized in certain steps. All of these steps were governed with a clear geometric order.

Only the methods which depend on the geometrical principles are demonstrated, by presenting the steps which the researcher used to generate the decoration pattern design, followed by applying every step of the methods on one pattern example.

We will present the following methods:

1- Abu'l-Wafā al-Buzdjāni (ca. 940–998).
2- E. Hanbury Hankin's "polygons-in-contact" technique, 1925
3- Isam El Said, "Compass and Ruler Method", 1962.
4- A.K. Dewdney "The Over Under Rule", 1993.
5- Aljamali, "Normalization and exploration design method", 2003.
6- Eric Broug, "Step-by-Step" guidance, 2008.

In all of these methods it is found that a hidden geometric order plays the role of the secret factor which controls the pattern design.

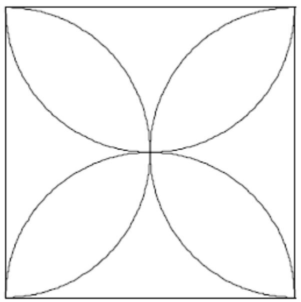
1- Method 1: Abu'l-Wafā al-Buzdjāni (ca. 940–998).

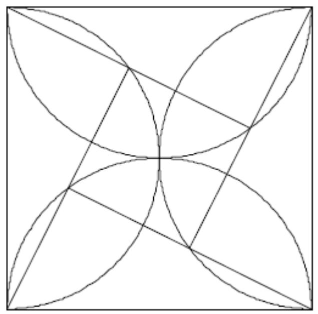
* He was one of the many Islamic mathematicians who developed geometric techniques that proved useful to artisans in creating the highly symmetrical ornamentation found in architecture around the world today.
* He showed that mathematicians taught geometry to artisans by means of cut-and-paste methods, and of geometrical figures that had the potential to be used for ornamental purposes.
* He described several constructions made with the aid of straight edge and "rusty compass" (a compass with a fixed angle).
* The Method's Notion can be described in the following four points:

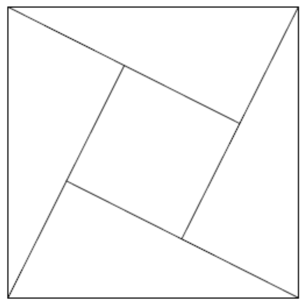
1- Constructing a perpendicular at the end point of a line segment.
2- Dividing segments in equal parts and bisecting angles.
3- Constructing a square inside a circle.
4- These constructions form the basis for creating many of the symmetric patterns of all artisans at that time.

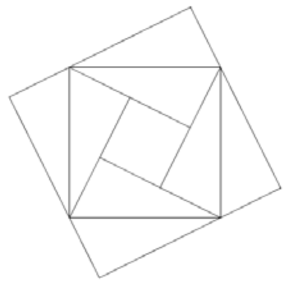
* Applying the steps of the method in one example will be as follows:

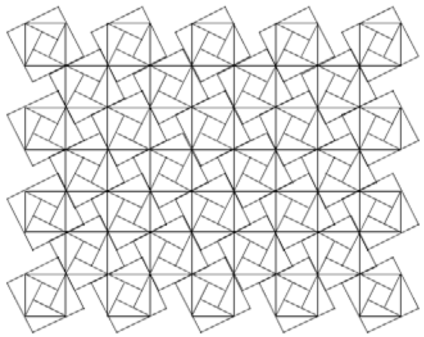
Step 1: Construct semicircles on the four sides of a square.
Step 2: Choose a point on each semicircle and draw a line from it to the vertex of the square.
Step 3: Remove the semicircle.
Step 4: A square is revealed, which may be divided into two smaller squares.
Step 5: Add four right triangles to produce a larger square.
Step 6: Extend the pattern in two perpendicular directions.


Step 1 :- Semicircles


Step 2:- Smaller Square


Step 3:- Assemled Square


Step 5:- Additional Square



Step 6 :- Tiling by Translations

2- **Method 2: E. Hanbury Hankin's "polygons-in-contact" technique, 1925.**

* The Method's Notion can be described as follows:

"In making such patterns, it is first necessary to cover the surface to be decorated with a network consisting of polygons in contact. Then through the centre of each side of each polygon two lines are drawn. These lines cross each other like a letter X and are continued till they meet other lines of similar origin. This completes the pattern."

* Applying the steps of the method will be as follows:

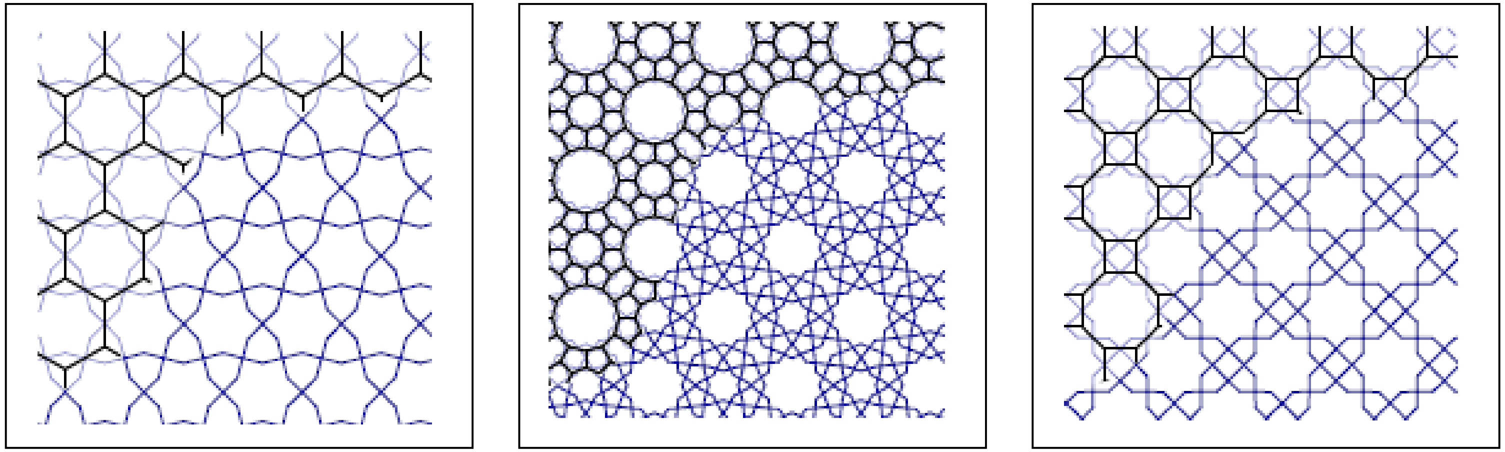


Figure 4-28: Two-point star patterns constructed by using Hankin's method.

3- Method 3: Isam El Said's "Compass and Ruler Method", 1962.

* The Method's Notion can be described as follows:

1- The understanding of the complete design can be achieved by understanding the significance of the small part and its role in the complete design.
2- The traditional craftsmen would not calculate angles in order to make their compositions.
3- Their tools were a compass and a ruler. With these tools they drew circles and lines and by connecting intersections of these circles and lines they created patterns.
4- From a circle it is possible to generate any regular polygon once the circumference is divided equally into the required number of parts and the points of division are joined with straight lines. The first step of dividing the circumference into three, four and five equal parts or their multiples, determines the subsequent grid pattern(s) and repeat units while the radius or diameter of the circle can be taken as a unit measure.

* Applying the steps of the method will be as follows:

Step 1: Divide the decorated surface into an equal number of circles.
Step 2: Divide every circle into a specific number of sectors.
Step 3: Draw a number of assistant circles
Step 4: Draw a number of assistant lines.
Step 5: Determine the intersection between the circles and the lines.
Step 6: Join the previous intersection points.
Step 7: The final shape of the decoration pattern is created.

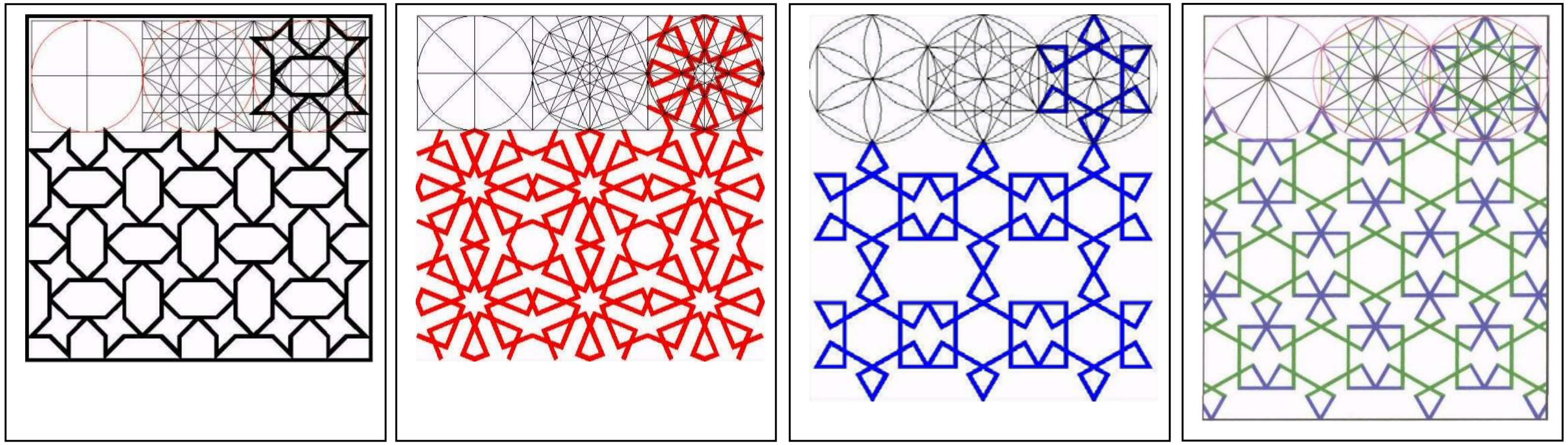


Figure 4-29: Ruler/compass decoration design method

4- Method 4: A.K. Dewdney's "The Over Under Rule", 1993.

* The Method's Notion can be described as follows:

This method for constructing designs is based on reflecting lines through a regular arrangement of circles.
There are four possible symmetry operations that can be done on a plane imprinted with a pattern. These symmetry operations are as follows: translation, reflection, rotation, and glide reflection (translation followed by reflection).

* Applying the steps of the method will be as follows:

Step 1: Set up a grid of points (the grid is: triangle, square, rectangular or hexagonal).
Step 2: Draw a circle at each of the grid points.
Step 3: Select points that are evenly spaced around the circle.
Step 4: Join the points on each circle with points on other circles
Step 5: Thicken each line by drawing a parallel line on each side.
Step 6: The crossing is tackled by using "the over under" rule in order to make overpasses and underpasses.
Step 7: The final stage in the creation of the design involves inking and coloring.

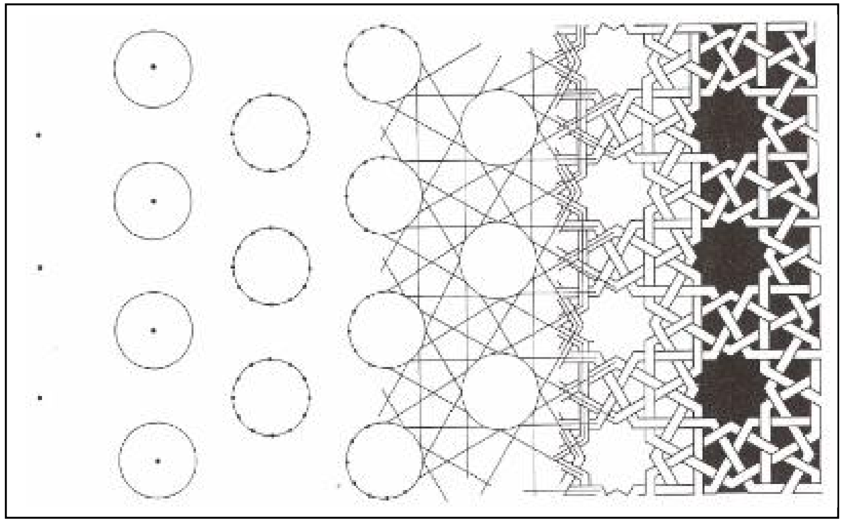


Figure 4-30: Various stages of the over under rule method in the construction of Latticework

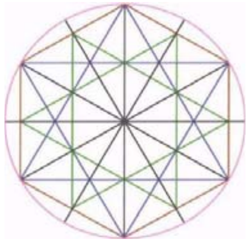
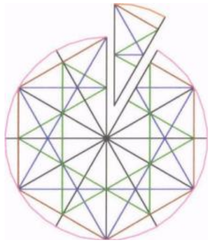
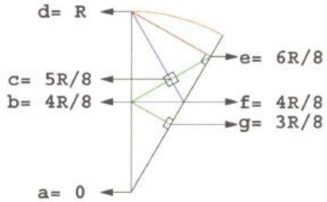
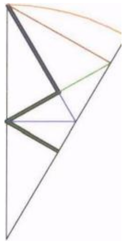
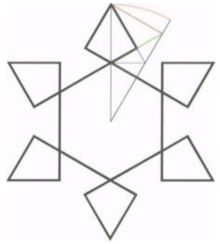
5- **Method 5: Aljamali, "Normalization and exploration design method", 2003.**

* The Method's Notion can be described as follows:

This method explores Islamic geometric patterns (IGP) based on normalization (formulation) of the sub-motif grid (the smallest portion of the symmetrical unit pattern) within the unit patterns that literally hold the entire form of the unit pattern.

* Applying the steps of the method will be as follows:

Step 1: Unit pattern grid identification.
Step 2: Sub-motif grid identification.
Step 3: Sub-motif grid formulation.
Step 4: Unit pattern automation.

 Fig (1) Identification of unit pattern grid	 Fig (2) Identification of sub-motif grid	 Fig (3) formulation of sub-motif grid
 Fig (4) Automation of sub-motif pattern	 Fig (5) Automation of motif pattern	 Fig (6) Automation of unit pattern

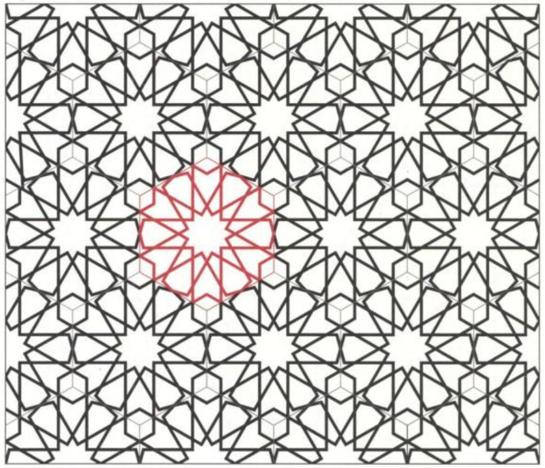
6- **<u>Method 6: Eric Broug's "Step-by-Step" guidance, 2008.</u>**

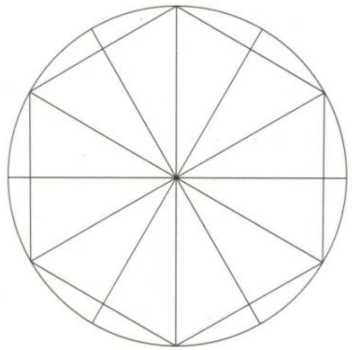
* The Method's Notion can be described as follows:

Every one of the Islamic geometric patterns has its own hidden geometric order, so the hidden geometric order which controls the pattern design is different from place to place all over the Islamic world.

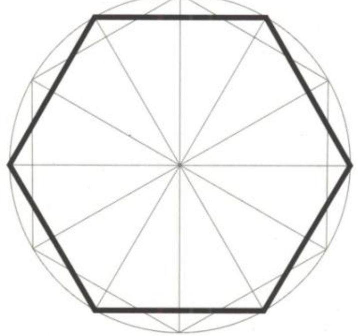
One example from Mamluk architecture in Egypt and the hidden geometric order in its design are presented.

* Applying the steps of the method on the Mosque of al-Nasir Mohmed ibn Qalawun will be as follows:

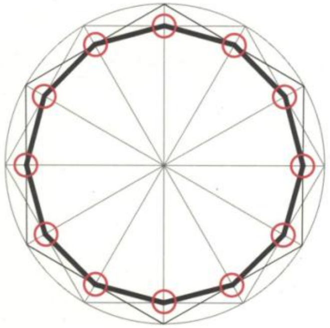




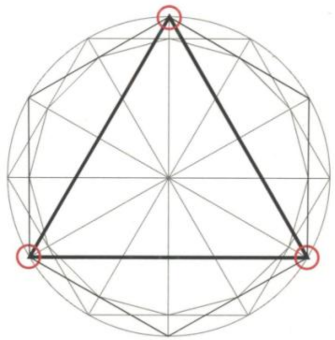
1 In pencil draw a hexagon in a circle with six intersecting lines (> 13–15).



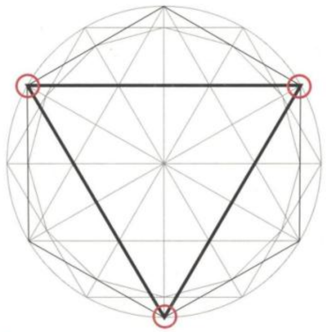
2 Draw a second hexagon that fits exactly int the circle as shown.



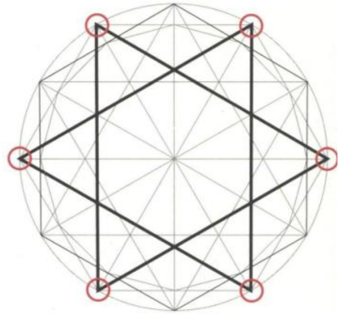
3 Connect the twelve ringed intersections.



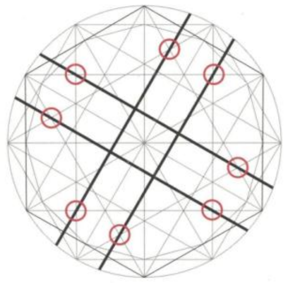
4 Connect the three marked points to create a triangle.



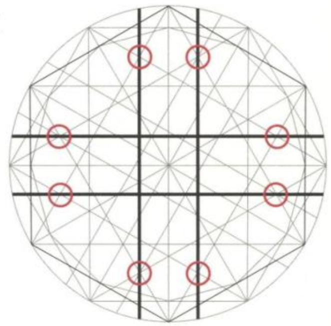
5 Draw a second triangle.



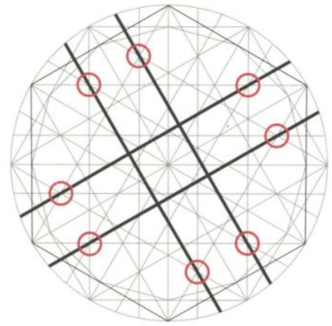
6 Add another pair of triangles using the six ringed intersections as markers.



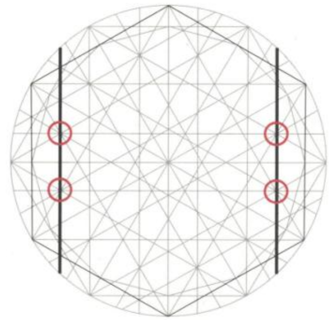
7 You may find it helpful to mark the circled intersections first before drawing the lines in the next few steps. Draw two pairs of parallel lines that run through the ringed intersections and extend to the circumference of the circle.



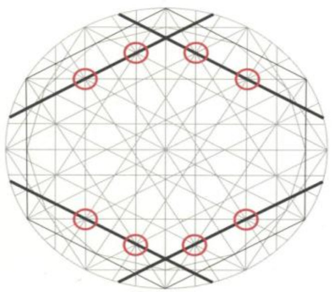
8 Draw another two pairs of parallel lines using the ringed points as markers.



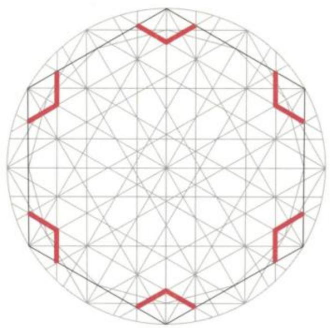
9 Repeat the process once again, using the ringed intersections as markers.



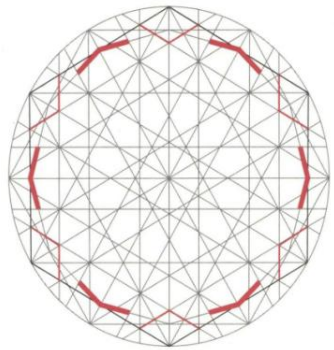
10 Draw two parallel lines that run vertically through the circled intersections and extend to the circumference of the circle.



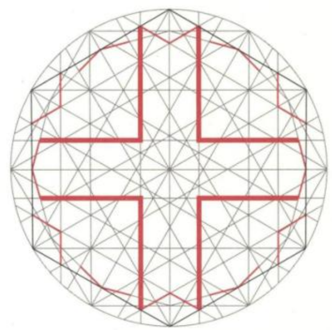
11 Connect the eight circled points with four lines that extend to the circumference of the circle.



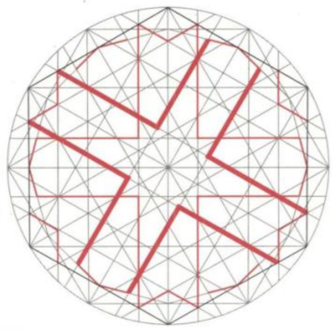
12 Now take a pen and ink over the six pairs of lines, as shown.



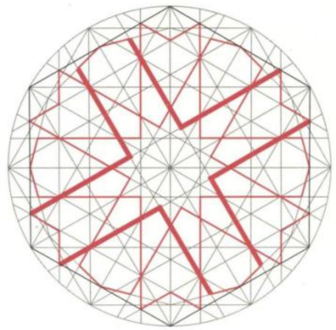
13 Now ink over these lines.



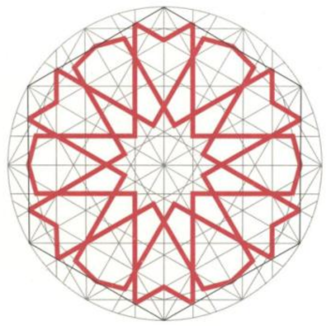
14 Draw eight lines which link up with some of the existing lines in pen to form a cross.



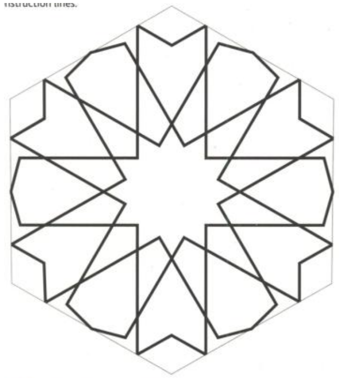
15 Form a second cross.



16 Form a third cross.



17 The pattern with the construction lines.



18 The pattern without the construction lines.

4.4. Conclusion

The Mamluk architect developed and applied the geometrical systems in architecture. They developed the geometrical design methods to guide the thought process of generations to come. The result of their pioneering work became the hallmark of Islamic architecture itself, and led to the birth of some of the best designed buildings in the world.

The ways Mamluk architects shaped space are determined not only by traditionally acknowledged premises of technology, function and culture, but also by the application of geometrical relationships, which are as a rule, stable and universal. For this reason, the suggestion of the geometric generative technique for the design of madrasa buildings can have important meaning, not only theoretical, but also practical, because it should lead to a better understanding of the religious building design.

By using the geometrical relations the Mamluk designer could enforce desired spatial configurations of building components and spaces. In Madrasa design there was a geometrical unity, besides the geometrical complexity, which generates a plurality of inherent layers in Madrasa design (layer of axes, layer of points, layer of plans, layer of functions, and layer of spaces or volumes). The geometric generative technique presents and demonstrates how the Mamluk architect could manipulate with these layers in the design of Madrasa building. The geometrical composition of madrasa buildings can be read as simple geometrical volumes symmetrically excavated along the inside to the outside axis. The Mamluk architect relied on studying the mutual relationship between his building's visual connections elements (entrance, minaret, and dome) and the visual elements which were distributed in the surrounding urban context. In order to emphasize his notions besides respecting the effect of the urban context on the building design, and from his studying to these mutual relations he could determine the position of his visual elements inside his building composition design. There is no doubt that the urban context of the city influenced the Mamluk architect to reach many urban values in his religious building design. From the geometric generative technique could be understood the role of urban design in Mamluk architecture in general and in the design of madrasa buildings in particular.

The design processes in Mamluk architecture depend on the architect's experience, which is gained from his education and training. This experience mainly depends on three types of science: geometry, mathematics and the Shari'a laws (Fiqh). Geometry helps him make the design and lay it out on the building site. Mathematics helps him calculate the amount of materials he needs on his building construction. The Shari'a laws help him study the relation between his building and the surrounding urban context.

There is an inherent scheme controlling the design of Madrasa building. The design starts with determining the centre points, as a references points of the building main spaces, and then by using the geometric operation (symmetry, addition, subtraction, rotation,…etc) the designer can generate all the building design. The main centre points play the role of the quickly available reference points for the guideline system of design. This chapter emphasizes the fact that there is a standardized or basic plan determining the relative positions and the proportions of madrasa building. This chapter also demonstrates the design method in the Mamluk era and explains how the Mamluk architect designed by expressing the role of geometry in the design process of Madrasa buildings.

This chapter does not try to provide recipes for the construction of a particular architectural form, whose instructions had to be followed step by step, but it also tries to explain the basic geometric rules, which the designer can depend on them in his design, and also the basic geometric forms, which can be combined in endless variations. For example, when the juxtaposition of two shapes is no longer possible because of the high degree of independence between these two forms, or simply because it is no longer considered satisfactory. The form must be processed and transcribed in a new geometry, instead of trying to hide or mitigate the disruptive element. It is rather used positively to create a new form of a more sophisticated geometry. Geometry then becomes the determining factor in madrasa composition.

Design Method

Geometry

Islamic Architecture

Research Skeleton

Introduction

The first part | The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part | The Analytical Study and the Field Study

Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A | A Computer-Aided Generator for Madrasa Buildings Design

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- Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings
- Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A — A Computer-Aided Generator for Madrasa Buildings Design

5. Chapter Five: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

5.1. Introduction

In this chapter the geometric order in some madrasa buildings of the Mamluk period is demonstrated by presenting the geometric order in two aspects of the building:

Firstly: the geometric order in the building space design,

Secondly: the geometric order in the building facade design

This is done by applying the geometric generative technique to the building space design and the geometric generative technique to the building facade design and by presenting the role of hidden geometric order in the design process. It is shown how the geometric generative technique can be an effective tool to generate the design of a madrasa building.

This geometric technique is applied in seven madrasa buildings. The seven buildings that have been chosen are not "exceptional" in many ways. They have been selected according to three specific conditions:

1- According to time: they were built in the Mamluk era and share common Mamluk features.
2- According to place: they are located in Egypt, specifically in Islamic Cairo.
3- According to type of buildings: they are madrasas or complex buildings with the madrasa as their main component.

The outcome of this analysis results in a set of observations which show a certain relationship between building design and geometry, arising from the use of geometric order in architecture design, not only in these selected buildings but generally in the architecture of the Mamluk period.

5.2. The Geometric Order in Building Design

Detailed analyses of various designs of Mamluk madrasas are presented to illustrate how design idea and the layout of the building have been derived geometrically and by the use of compass and rope.

The geometric generative technique is applied to seven examples of madrasas in order to be shown that it is an effective tool for generating the design of the building. The seven buildings that have been chosen are not "exceptional" in any way; they have been selected randomly for their common Mamluk features. The results and observations of this analysis show the recurrence of a certain relationship arising from the use of the geometric methodology of design, not only in these selected buildings but more generally in the religious architecture of the Mamluk period.

5.2.1. Applying the Geometric Generative Technique for Building Space Design in the Case-study Buildings

Applying the geometric generative technique for building space design in the case study building will begin with a general description, followed by the building architecture description, concentrating on describing the layout, the plans, the facades, the minaret (the tower), the mausoleum (the patron's tomb); and finally applying the geometric generative technique on the building itself, and this will be in the following case-study buildings:

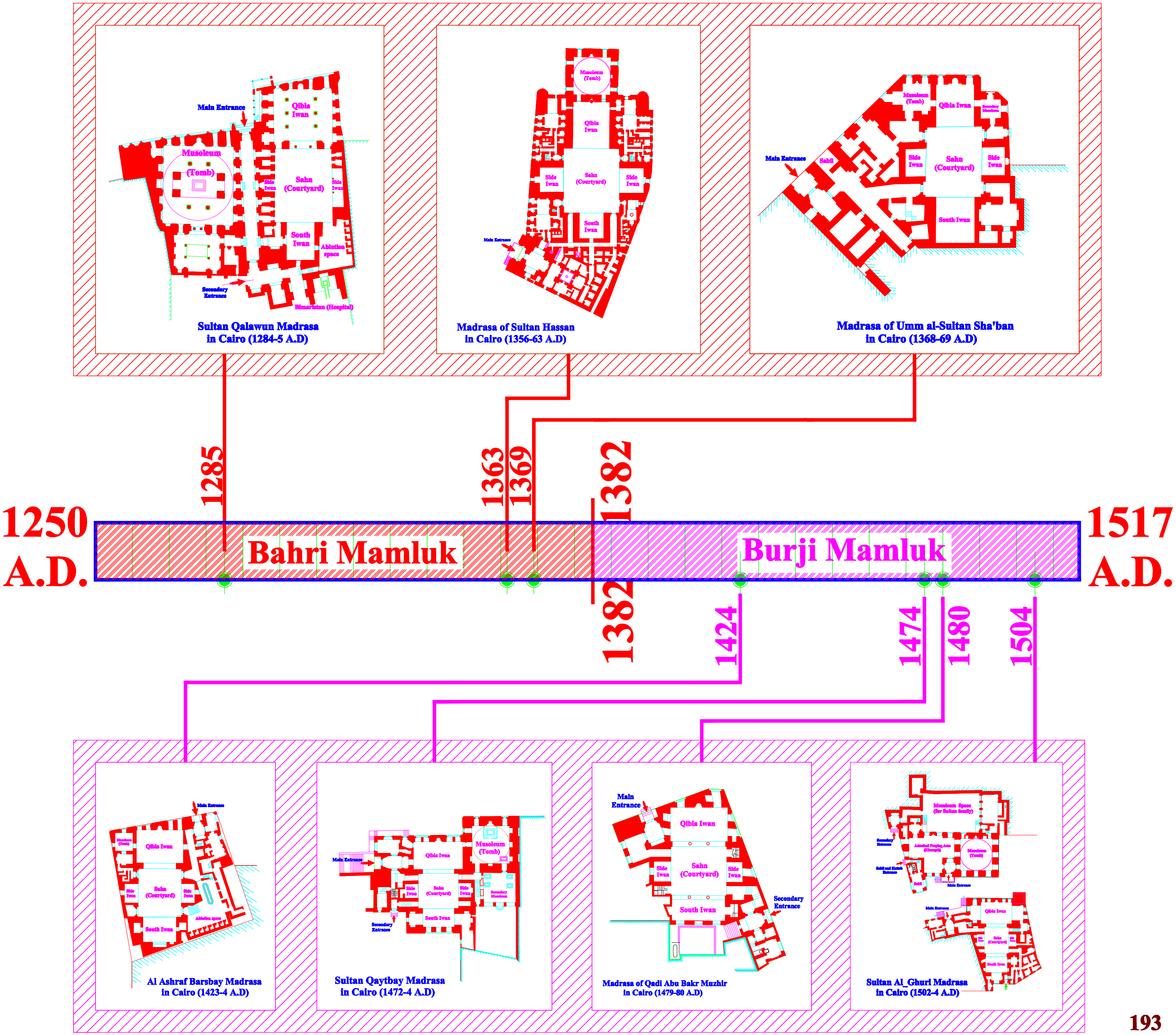
Bahri Mamluk

1- Madrasa of Sultan Qalawun (1284-5 A.D.)
2- Madrasa of Sultan Hassan (1356-63 A.D.)
3- Madrasa of Umm al-Sultan Sha'ban, Khawand Baraka (1368-9 A.D.).

Circassian Mamluk

4- Madrasa of Sultan El Ashraf Barsbay (1423-4 A.D.)
5- Madrasa of Sultan Qaytbay (1472-4 A.D.)
6- Madrasa of Qadi Abu Bakr Muzhir (1479-80 A.D.).
7- Madrasa of Sultan Qansuah al-Ghuri (1502-4 A.D.)

The Case-Study Buildings in the Bahri and Burji Mamluk Eras



5.2.1.1 Madrasa of Sultan Qalawun (1284-5 A.D.)

<u>1- General Description:</u>

The complex consists of the founders' mausoleum, madrasa, and the maristan (hospital). They were all built by Sultan al-Malik al-Mansur Qalawun. These three buildings form an architectural group of great value, as they are the only surviving complex consisting of three types of buildings (madrasa [school], mausoleum [tomb] and bimaristan [hospital]). The complex was located in al-Mu'izz Street.

Variant Names	* Madrasa of Sultan Qalawun. * Sultan Qalaoun Complex. * Complex of Sultan Qalawun. * Mausoleum and Maristan of Sultan Qalawn. * Sultan al-Mansur Qalawun Complex. * Madrasa-Mausoleum and Hospital of Sultan al-Mansur Qalawun
Street Address	Al-Mu'izz Li-Din Allah Street
Location	Cairo, Egypt
Date	13th (1284-1285 A.D.)
Style/Period	Mamluk (Bahri)
Building Types	Complex (Educational, Health Care, Religious)
Building Usage	Madrasa, Hospital, Mosque, Mausoleum

Table 5-1: General description of Madrasa of Sultan Qalawun

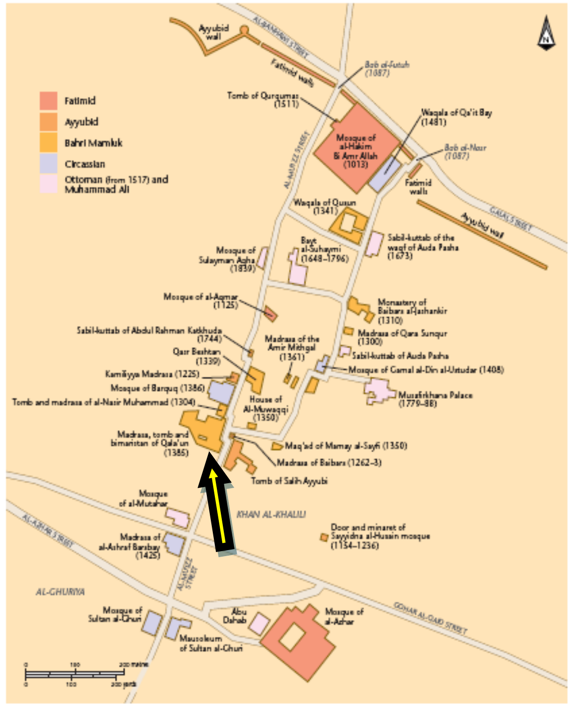


Figure 5-1 The site of the Madrasa of Sultan Qalawun

2- Architectural Description

a- The Layout

The building mass composition consists of two main masses. The first is the mass of madrasa and the second is the mass of the mausoleum. The mausoleum is connected to the madrasa by a long entrance passage. The plan of both spaces is shifted to accommodate the qibla orientation.

b- The Plan

The plan is of madrasa type. It has four iwans (two are small), overlooking an open sahn. The larger one is the qibla iwan. Its facade is composed of three arches, supported by two marble columns. It is divided into a main aisle, separated from the two side aisles by means of two arcades, supported by marble columns, as shown in Fig. (5-2).

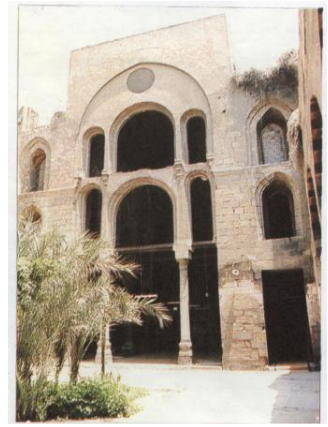


Figure 5-2: The facade of the qibla iwan from the sahn in Madrasa of Sultan Qalawun.

c- The Facades

The facade is composed of two parts. The northern part, on the right hand side of the main entrance, forms the facade of the mausoleum with its dome. At the end of this part stands the minaret. The southern part forms the facade of the madrasa. The whole facade is divided into arched panels, the arches of which are supported by marble columns. In the centre of each panel there are two windows. The upper one has stucco grilles pierced with beautiful geometrical designs, while the lower one has grilles of iron, as shown in Fig. (5-3) and Fig. (5-4).

The main entrance of this group is in Shari' al-Mu'izz. The two halves of the door are covered with brass plates, engraved and pierced with ornaments, as shown in Fig. (5-5). This entrance leads to a long corridor at its end is a door that once opened into the bimaristan.

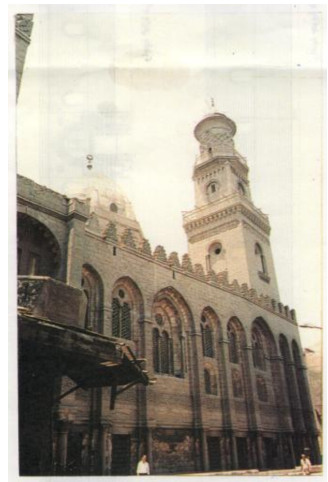


Figure 5-3: The facade of Qalawun Madrasa.

d- The Minaret

Qalawun's minaret is an imposing construction. The rectangular shaft and receding rectangular second story are built from stone. The third circular story is made of brick and decorated with stucco. The first story has horseshoe arches on cornices of stalacites. The second story has horseshoe arches and cushion voussoirs, see Fig. (5-6).
The third story of the minaret was constructed by Qalawun's son, Sultan al-Nasir Mohmed, after the 1303 A.D. earthquake had demolished the original. It's lace-like stucco carving is not in harmony with the rest of the minaret. An interesting band with vertical moldings resembling ancient Egyptian reed motifs marks the end of the circular part. Al-Nasir Mohmed's restoration of the minaret, with reference to the earthquake, is commemorated in the inscription band carved on the first story.

Figure 5-4: The facade of Qalawun Madrasa.

Figure 5-5: The entrance of Qalawun Madrasa

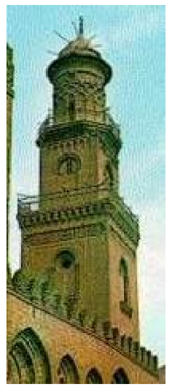


Figure 5-6: The minaret of Qalawun Madrasa.

e- The Mausoleum
The mausoleum is on the right-hand side of the great corridor. It has two entrances, one opens directly from the corridor into the mausoleum, the other from a small sahn. The central part is covered by a dome, supported by a ring of four piers and four granite columns with gilded capital, placed so that two columns alternate with two piers. The mausoleum is accessible via a small courtyard surrounded by an arcade with shallow domes.

<u>3- Applying the Geometric Generative Technique: (Technique Steps)</u>
The technique steps are applied to generate the design.

Pre-Design step:

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building entrance so that it is in relation to the entrance of the El Saleh Najm building, with which it is in confrontation. and to make a lobby in the street, as shown in Fig. (5-7).

b- Study the position of the dome

The designer chooses the position of the building's dome so that it is in relation to the dome of the al-Salih Najm al-Din building which is opposite, as shown in Fig. (5-8).

c- Study the position of the minaret

The designer chooses the position of the building's minaret so that it plays the role of the landmark to the site and the pedestrians can see it from a distance, as shown in Fig. (5-9) and (5-10).

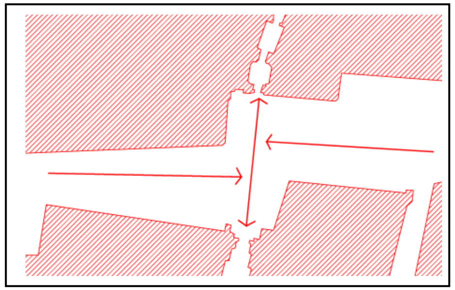


Figure 5-7: The position of Qalawun's entrance

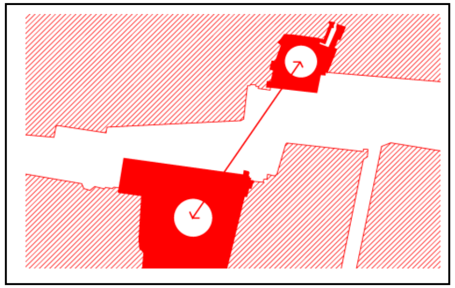


Figure 5-8: The position of Qalawun's dome

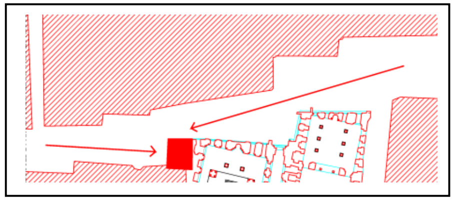


Figure 5-9: The position of Qalawun's minaret

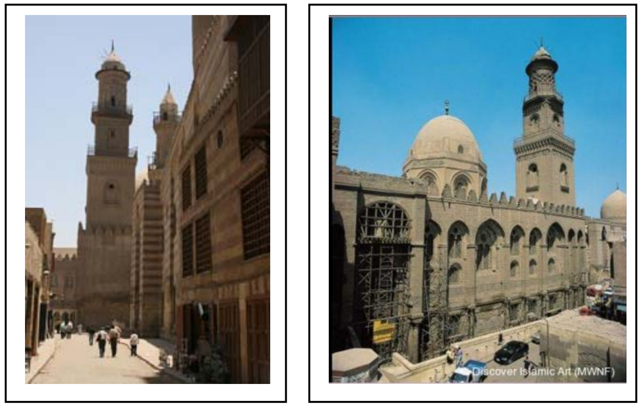


Figure 5-10: The view of Qalawun's minaret from the two sides of the street

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Figure (5-11).

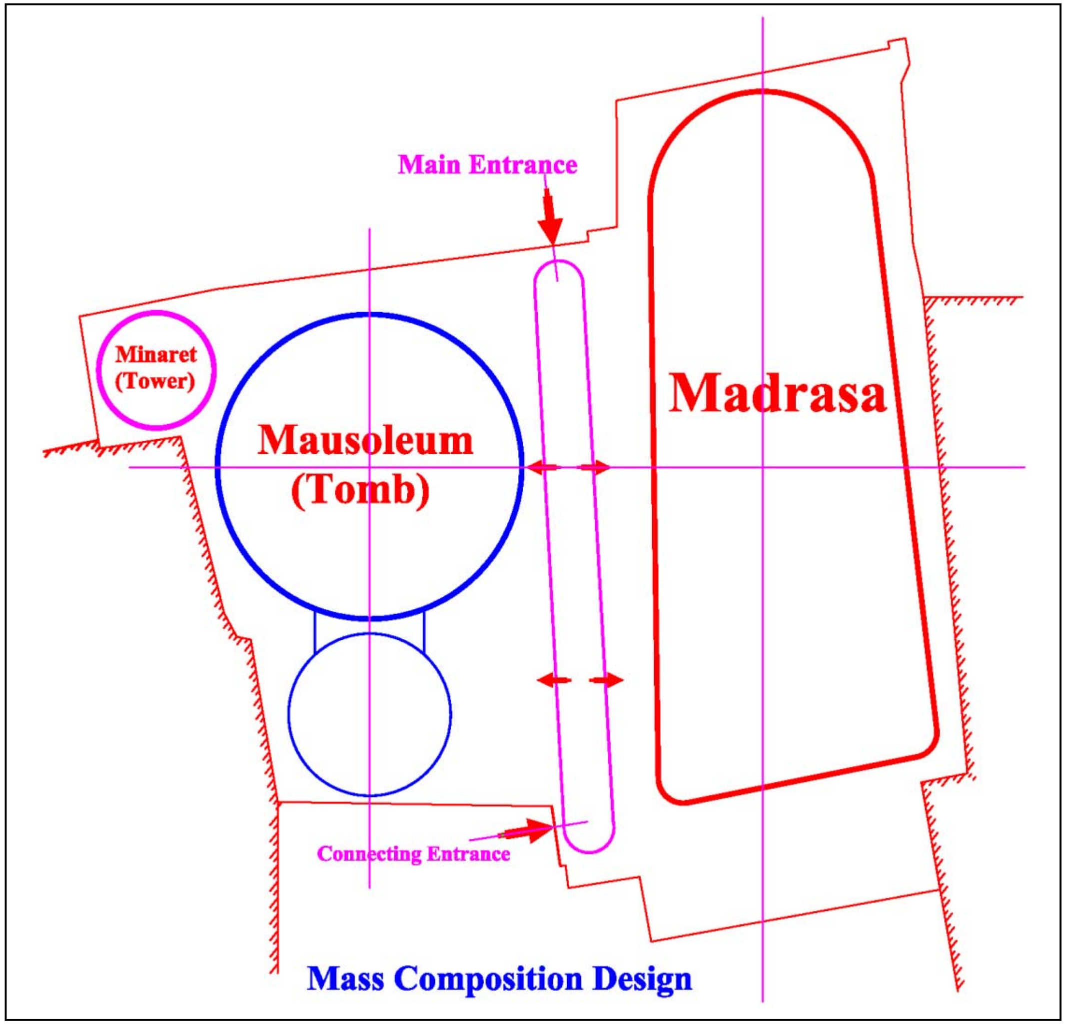
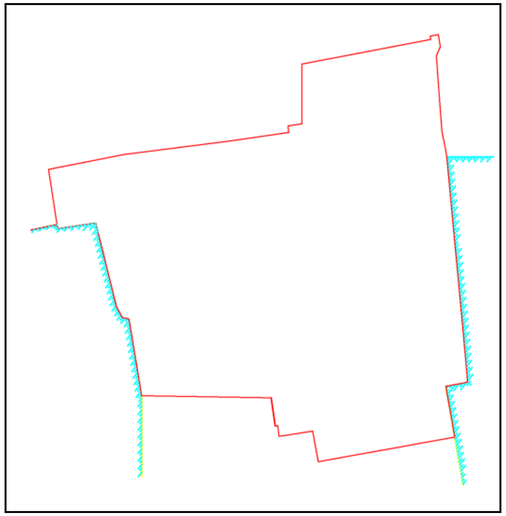
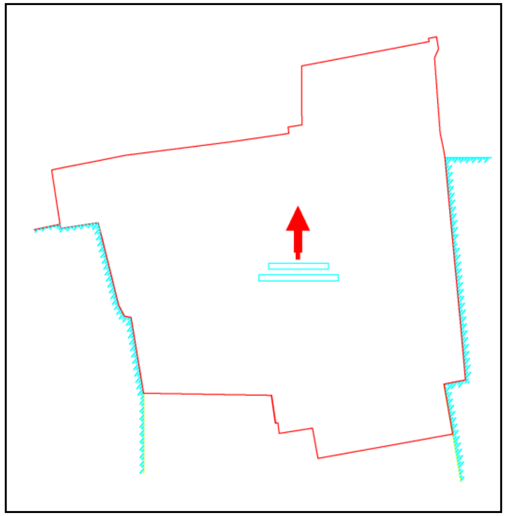


Figure 5-11: The composition of the masses in Madrasa of Sultan Qalawun

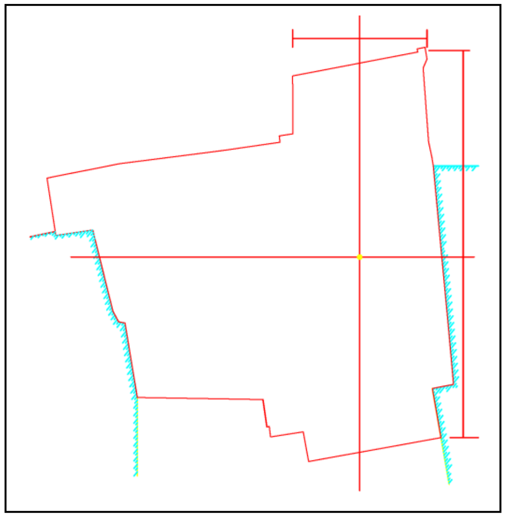
<u>1- First Step:</u> Determining the Site Boundary, the Qibla Direction and the Sahn's Centre Point.



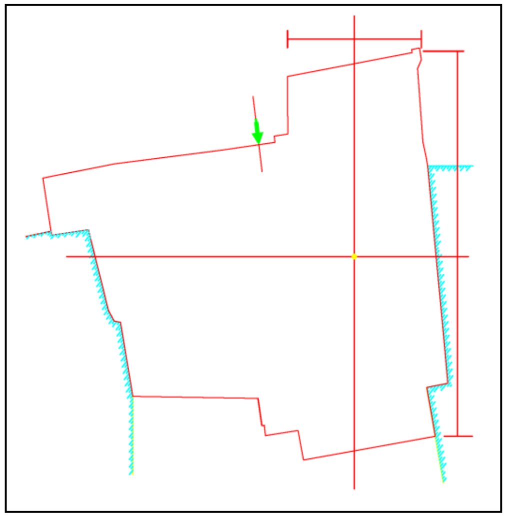
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

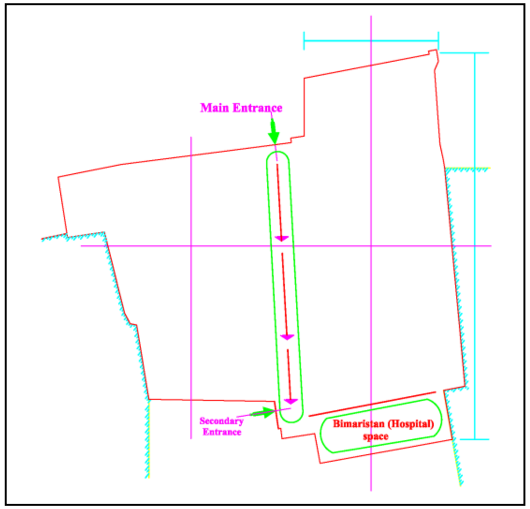


c- Determining the sahn's centre point

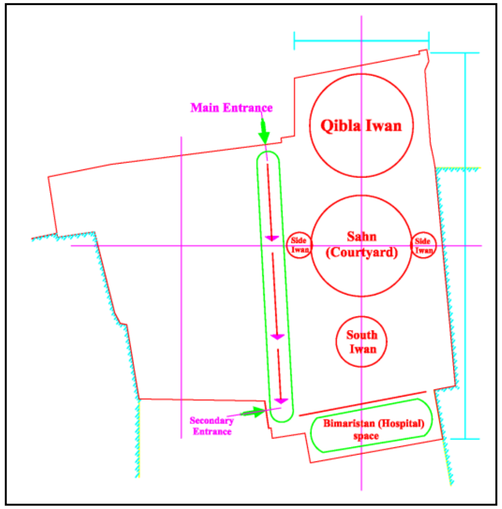


d- Adding the main entrance axis

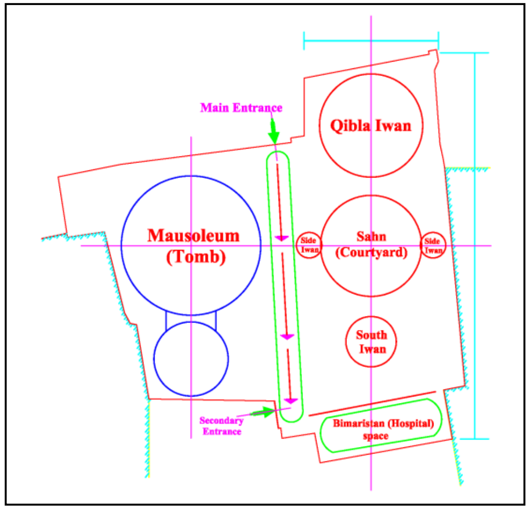
2- Second Step: Determining the Functions' Relationships and the Users' Circulations Diagram.



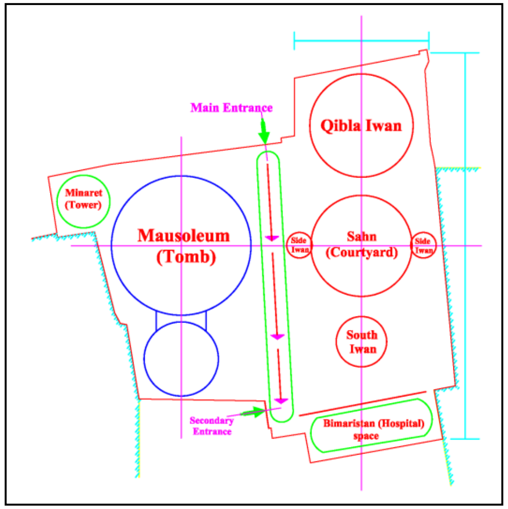
a- Determining the position of corridors according to the entrances



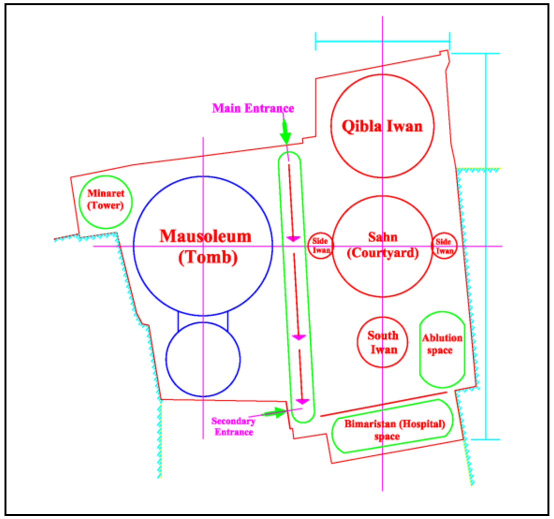
b- Determining the sahn and all iwans position



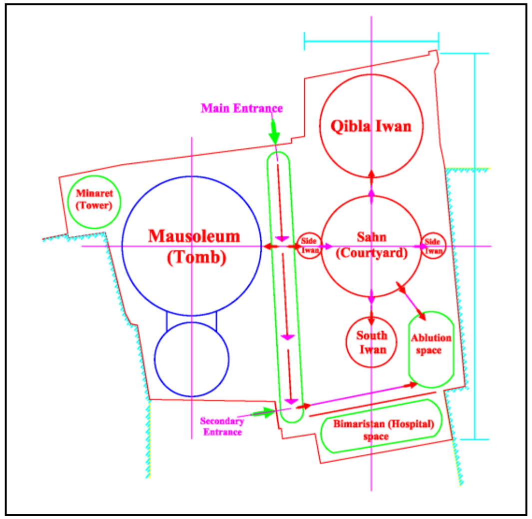
c- Determining the mausoleum position



d- Determining the minaret position



e- Determining the ablution space position



f- Determining the users' circulations between spaces

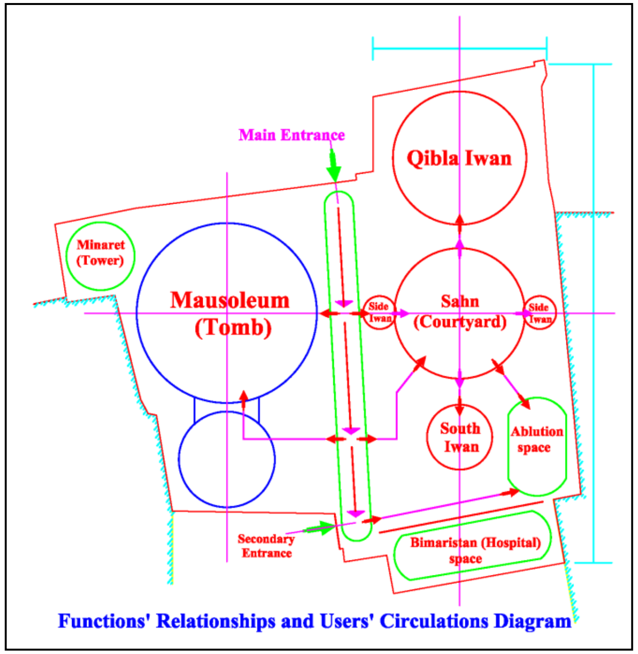
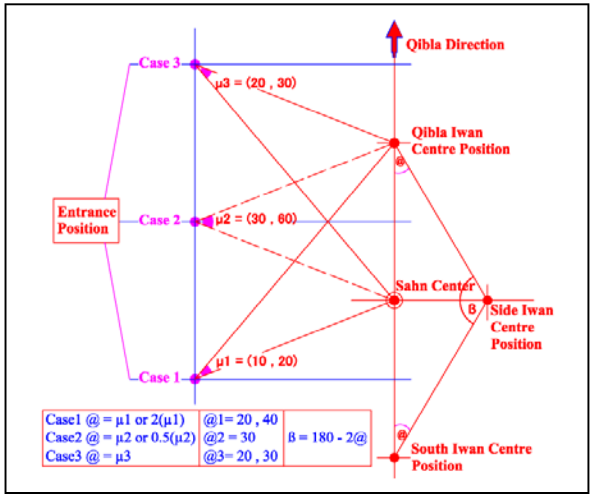
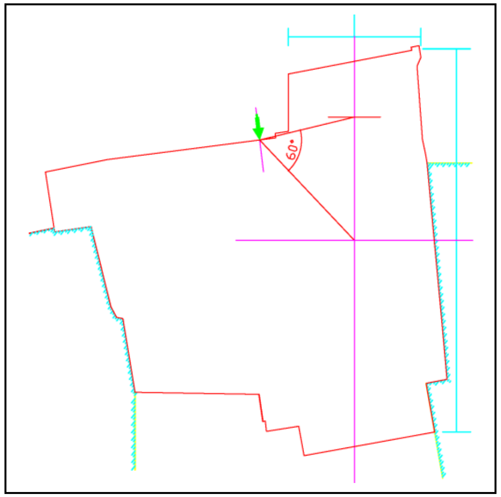


Figure 5-12 Determining the final functions' relationship diagram in Madrasa of Sultan Qalawun

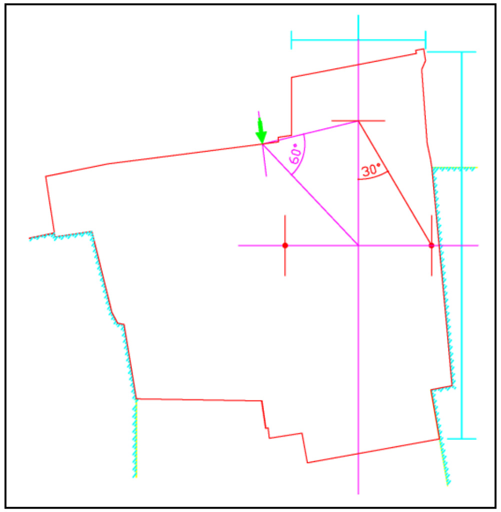
<u>3- Third Step:</u> **Applying the Hidden Geometric System** (Determining **µ**, **@** and **ß** angles).



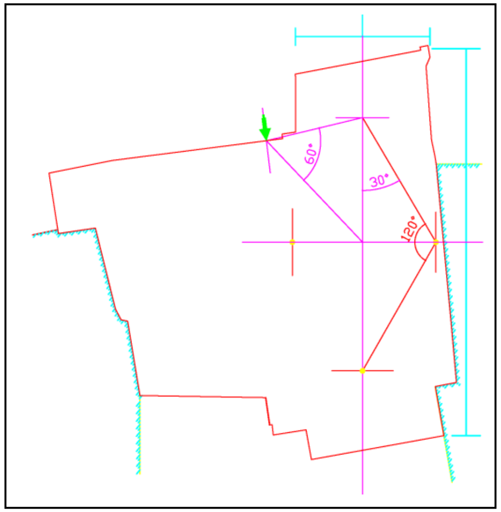
a- The hidden geometric system
(Determining the µ, @ and ß angles)



b- Determining the qibla iwan's centre point
(Applying the µ angle)



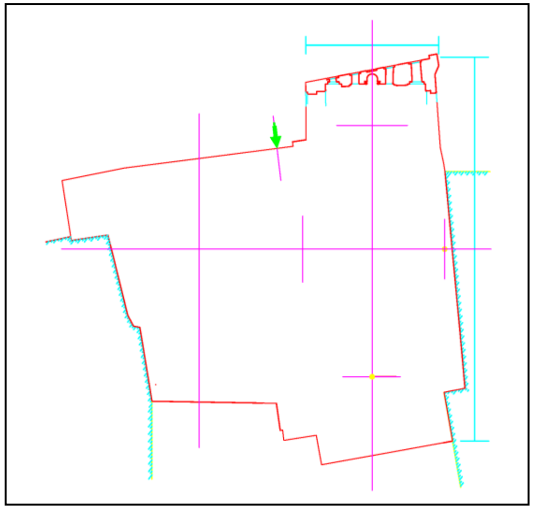
c- Determining the side iwans's centre points
(Applying the @ angle)



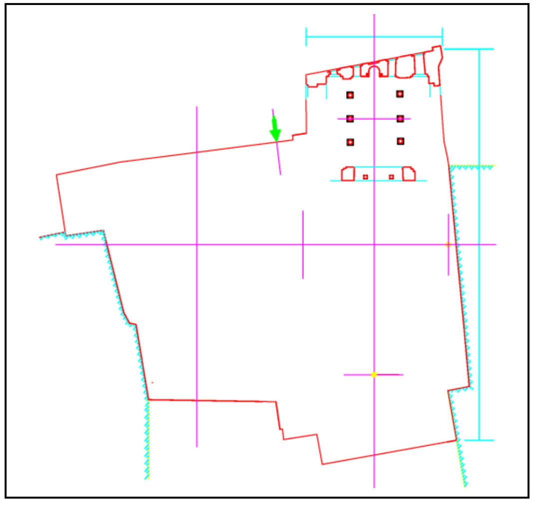
d- Determining the south iwan's centre point
(Applying the ß angle)

<u>4- Fourth Step :</u>- Generating the Building Plan's Design (the design of the building in 2D).

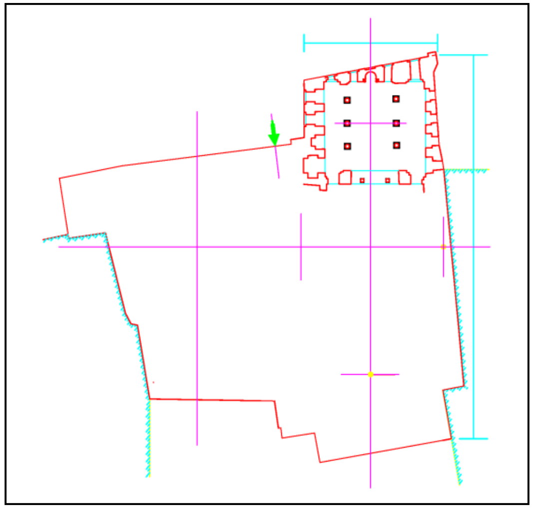
1- Generating the Qibla Iwan (Praying Hall)



a- Designing the qibla wall

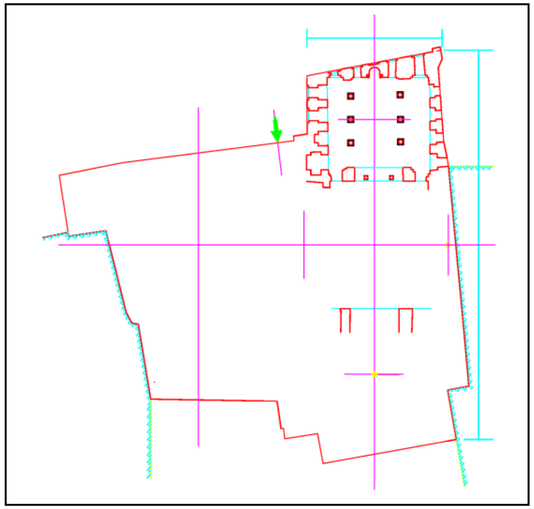


b- Designing the qibla iwan's entrance wall

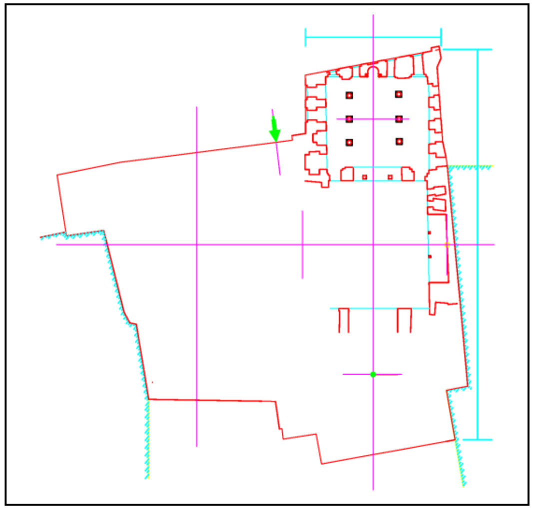


c- Completing the design of the qibla iwan

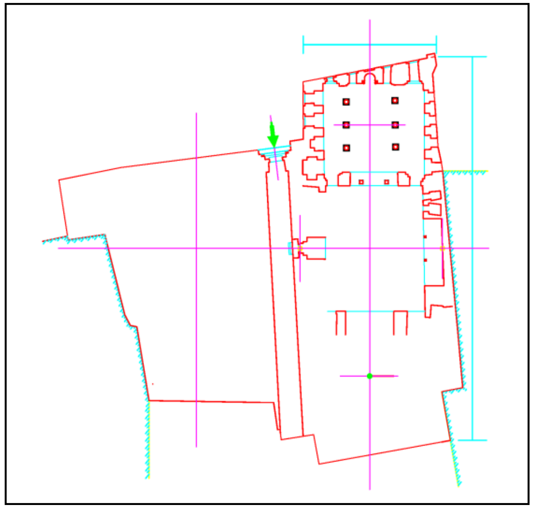
2- Generating the Sahn (Courtyard) and the Two Side Iwans



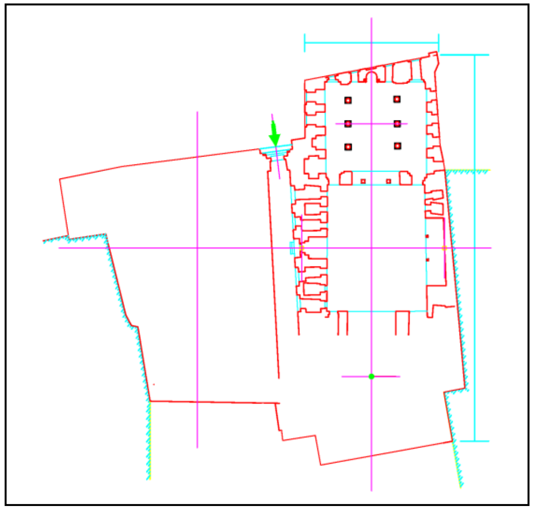
a- Beginning with the design of the sahn



b- Designing one of the side iwans

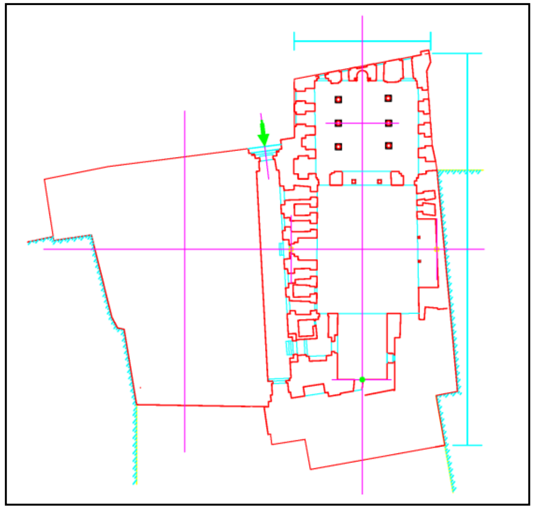


c- Designing the second side iwan

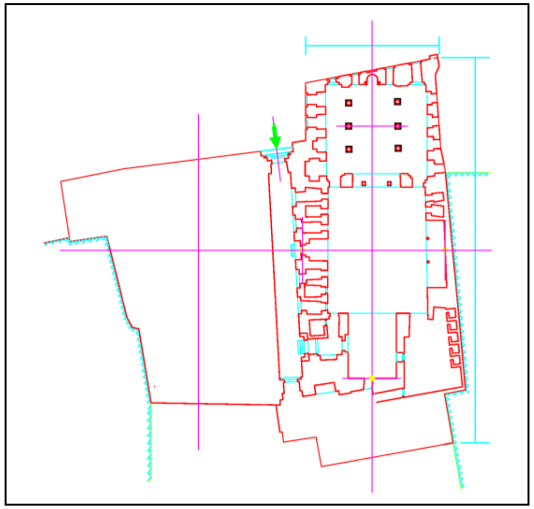


d- Completing the design of the sahn and the side iwans

3- Generating the South Iwan

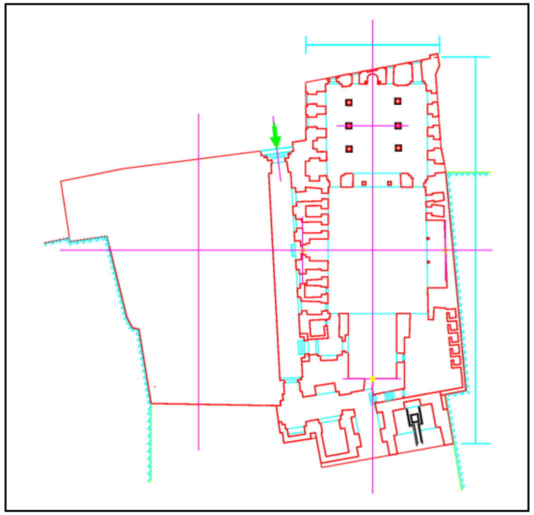


4- Adding Ablution Space

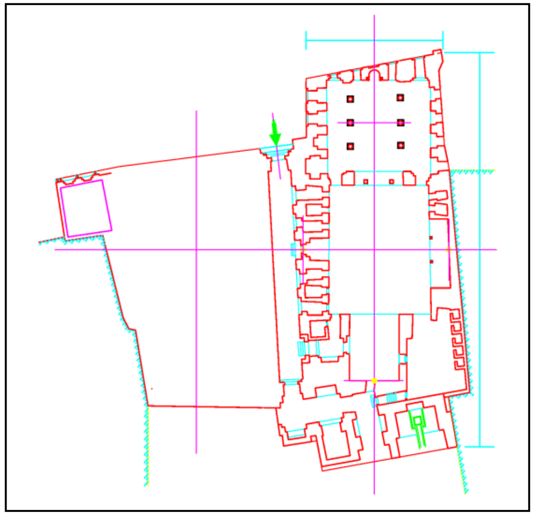


5- Adding the Entrance Design

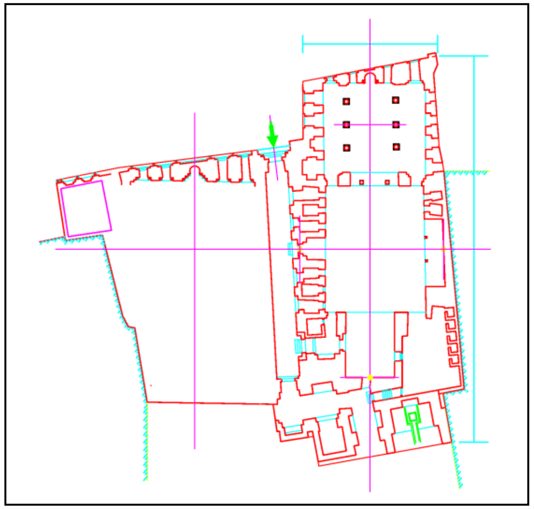
a- Placing the entrance components spaces
b- Designing the path from the entrance to the sahn
c- Placing the entrance cells



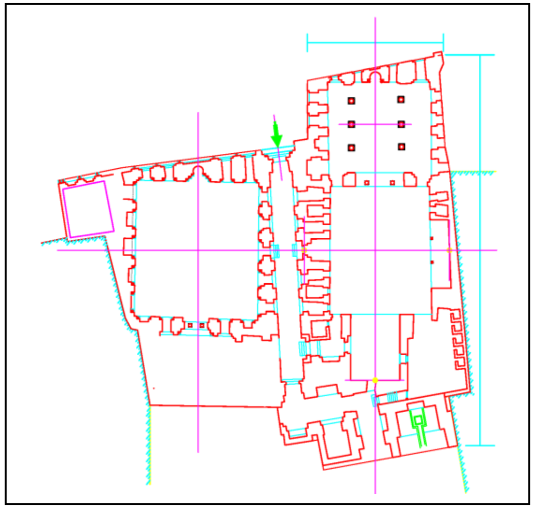
6- Determining the Position of the Minaret



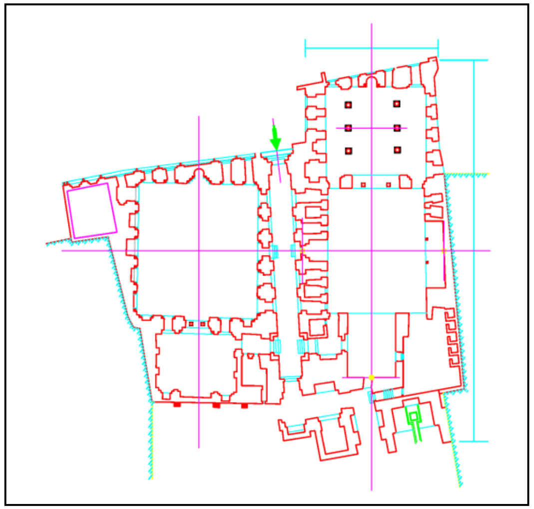
7- Generating the Mausoleum



a- Designing the qibla wall inside the mausoleum



b- Completing the main space of the mausoleum



c- Adding the approach space to the mausoleum

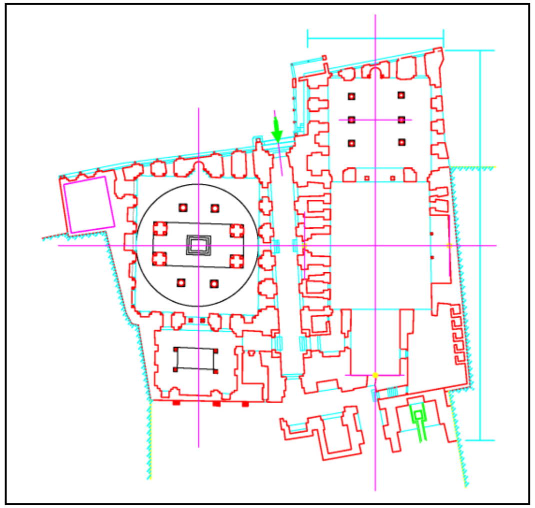


Figure 5-13: The final design of the mausoleum in Madrasa of Sultan Qalawun

8- The Final Building Plan with the H.G.D[1]. System

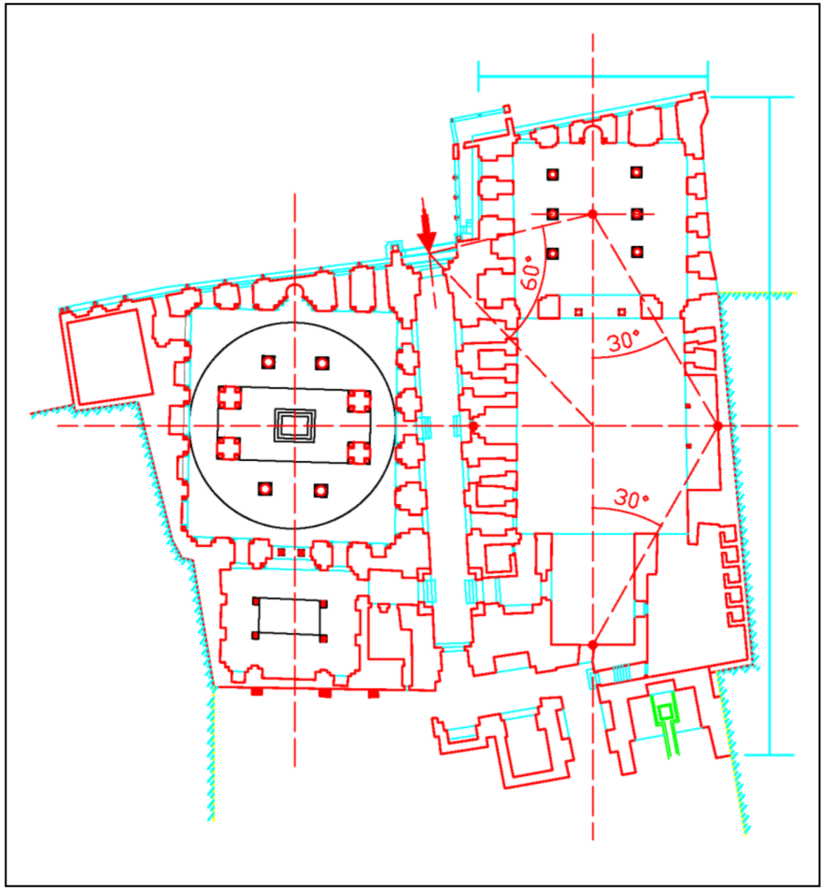


Figure 5-15: Madrasa of Qalawun's final plan with the H.G.D. system.

9- Generating the Final Building Plan

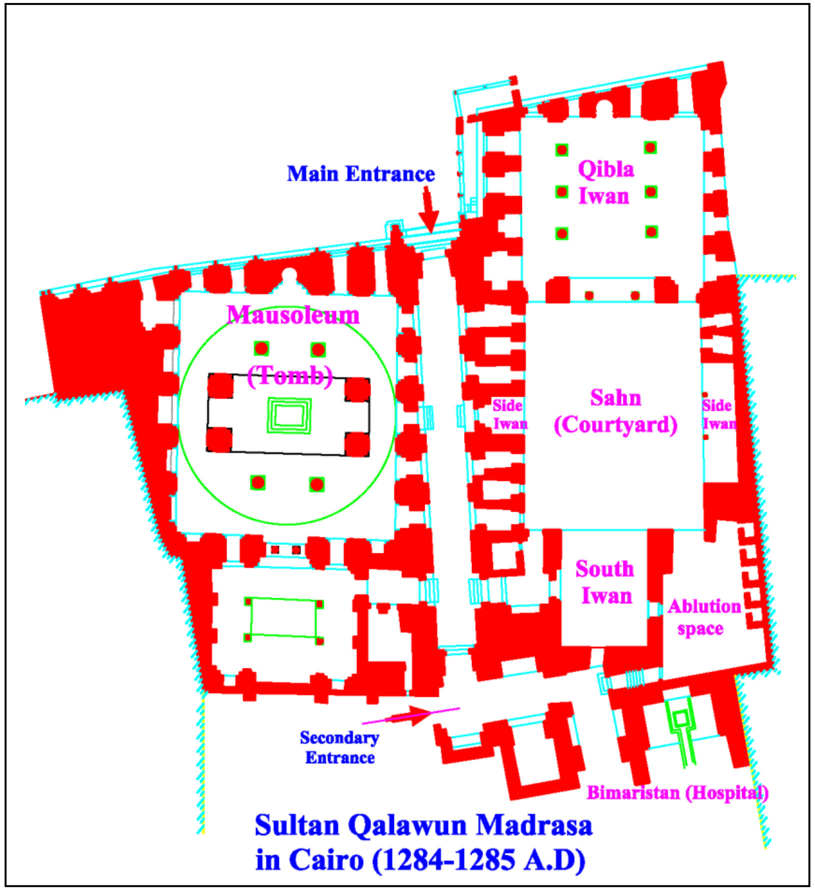


Figure 5-14: The final plan of Madrasa of Sultan Qalawun

[1] H.G.D. System : Hidden Geometric Design System

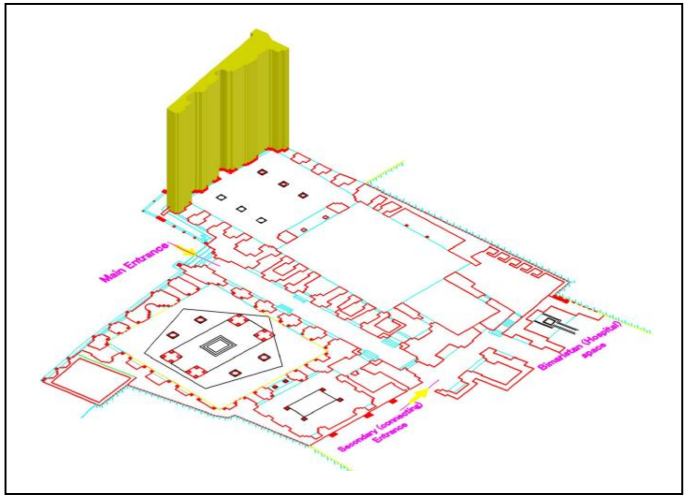
<u>5- Fifth Step:</u> Applying the Interior Space Design Rules.

These are the results of applying the interior space design rules in Madrasa of Sultan Qalawun:
* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.
* The entrance spaces are roofed and their height is equal to the building's total height.
* The design follows the opened courtyard type so the sahn is not roofed.

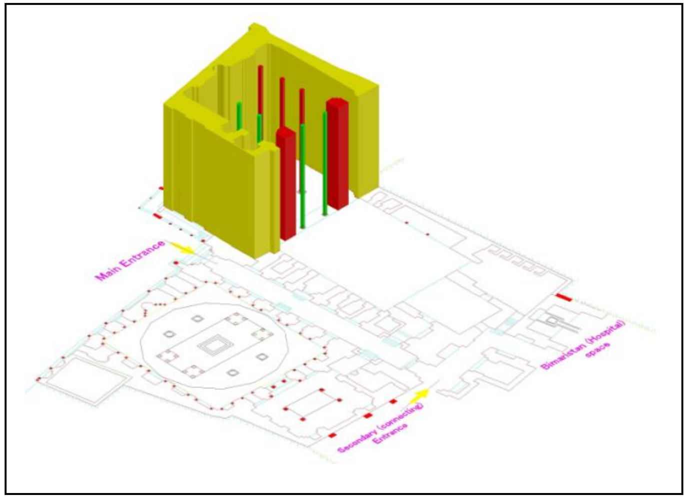
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans which he has designed into three-dimensional spaces.

<u>6- Sixth Step :</u>- Generating the Building Spaces' disposition (The Design of the building in 3D).

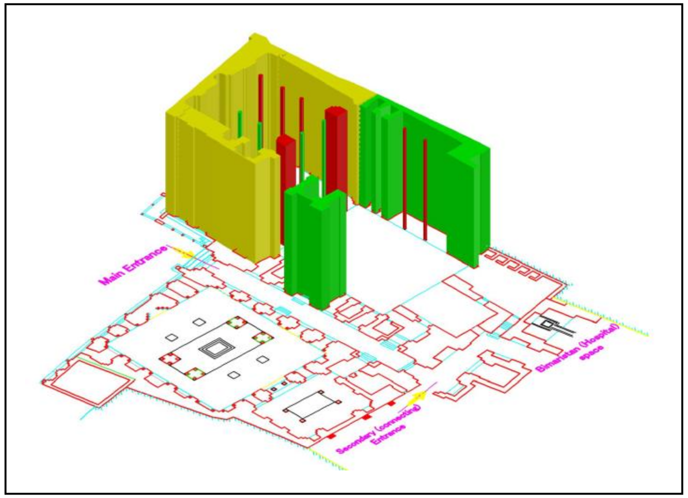
1- Constructing the Qibla wall



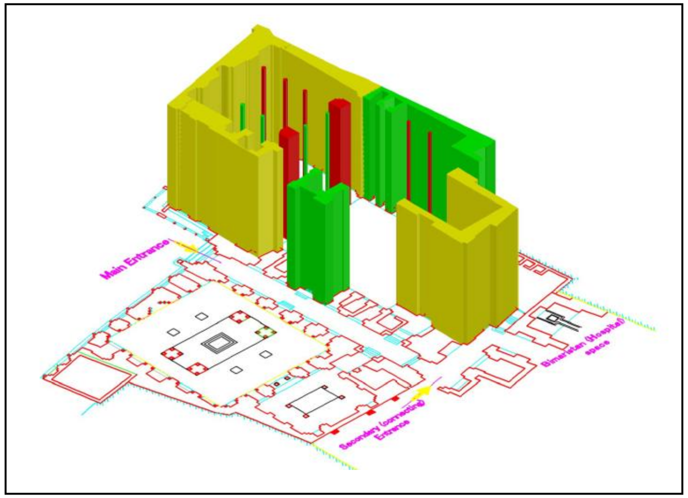
2- Completing the Qibla Iwan



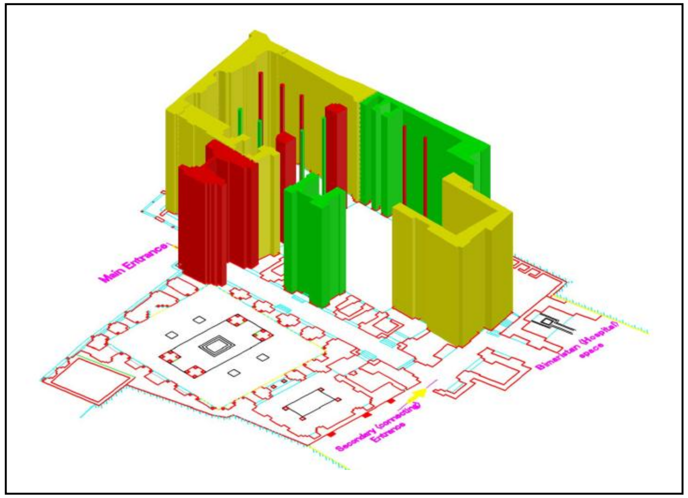
3- Constructing the Side Iwans



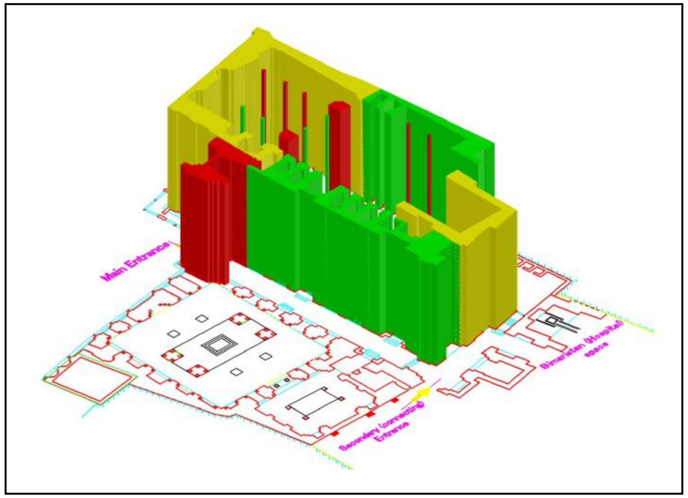
4- Constructing the South Iwan



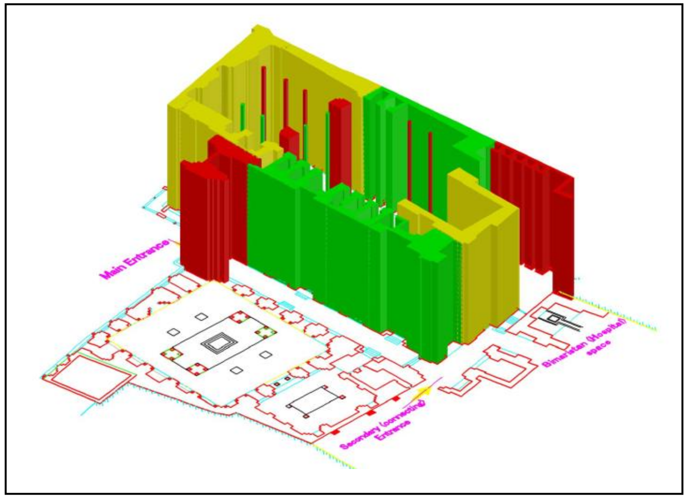
5- Constructing the Entrance and its Spaces



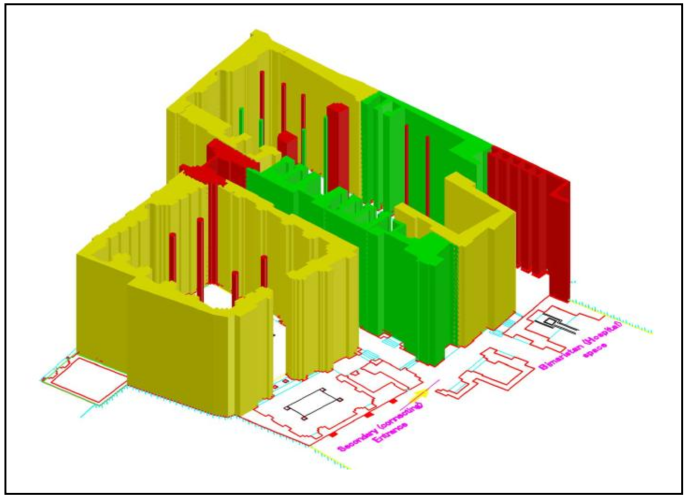
6- Completing the Iwans Cells



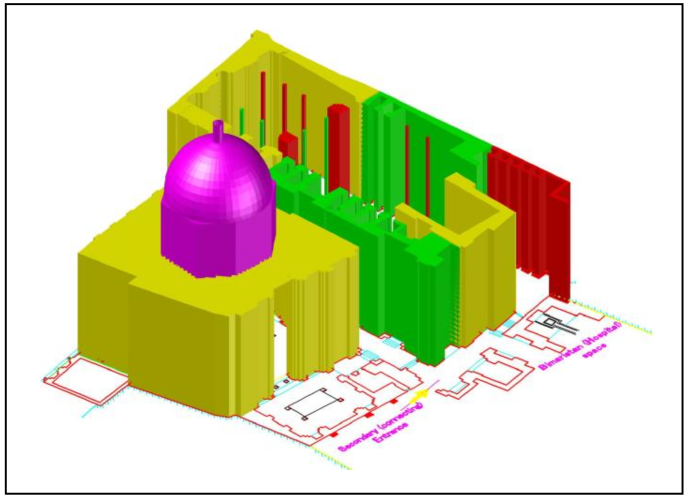
7- Constructing the Ablution Space



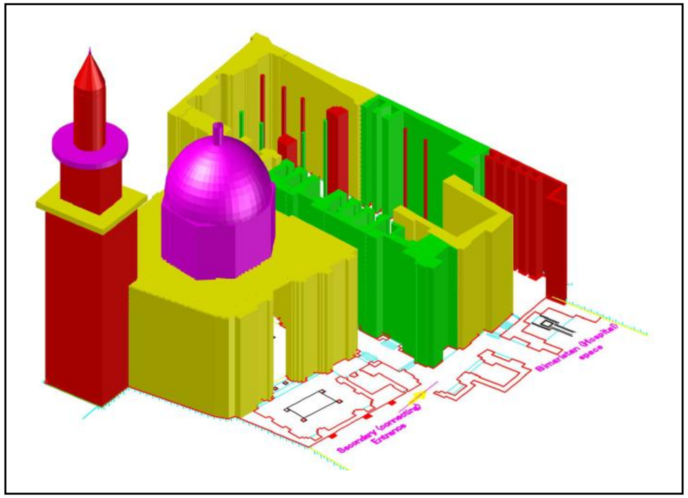
8- Constructing the Mausoleum



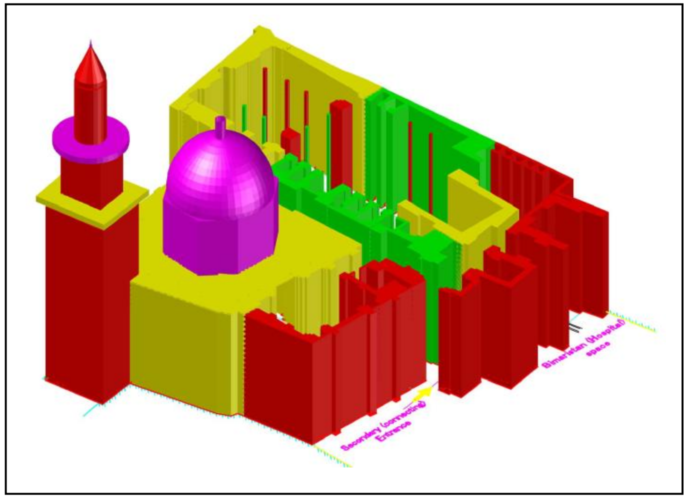
9- Constructing the Dome of the Mausoleum



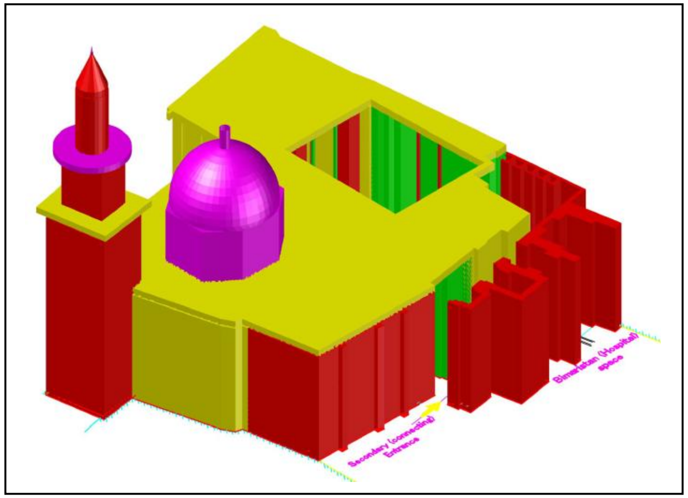
10- Constructing the Minaret



11- Constructing the Rest of the Building's Spaces



12- Roofing the Building



5.2.1.2 Madrasa of Sultan Hassan (1356-63 A.D.)

1- General Description:

The Complex of Sultan Hassan was built between 1356 and 1363 A.D., and included a madrasa, congregational mosque, and mausoleum. The free-standing complex, which had a monumental domed mausoleum flanked by minarets, only one of which survives, is located in a prominent position below the Citadel, toward which the monumental portal is oriented.

Variant Names	* **Madrasa of Sultan Hassan,** * Sultan al-Nasir Hasan, * Mosque-Madrasa-Mausoleum of Sultan al-Nasir Hasan, * Sultan an-Nasir Hasan Mosque, * Sultan al-Nasser Hassan, * Mosque of Sultan Hasan, * Madrasa and Friday Mosque of Sultan Hasan.
Street Address	Al-Qal'a Street
Location	Cairo
Date	14th (1356-1363 A.D.)
Style/Period	Mamluk (Bahri)
Building Types	Complex (Educational, Funerary, Religious)
Building Usage	Madrasa, Mausoleum, Mosque.

Table 5-2: The general description of Madrasa of Sultan Hassan

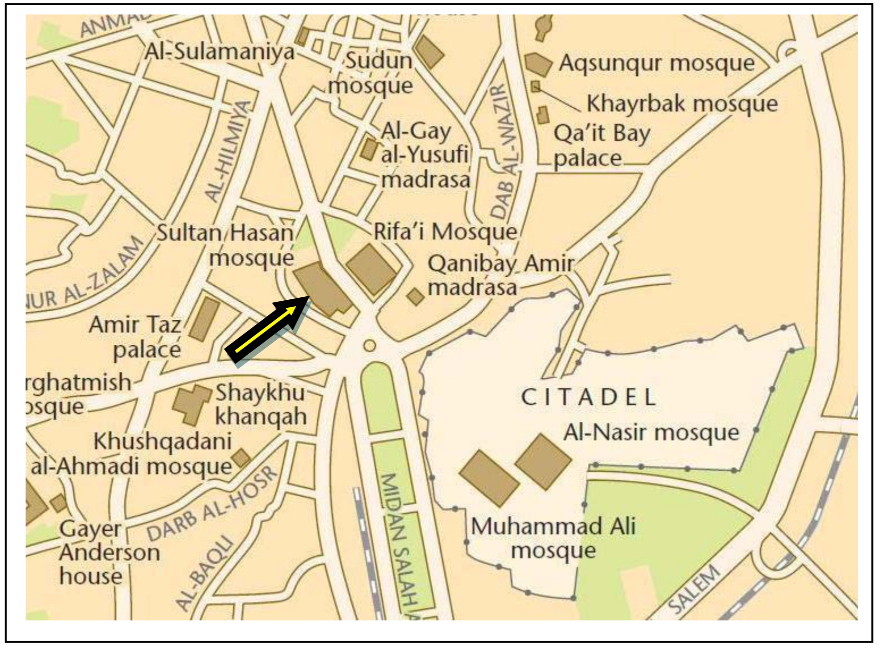


Figure 5-16: The site of Madrasa of Sultan Hassan

2- Architecture Description

a- The Layout

The complex consists of a group of distinguished and integral elements in a single mass. Its plan is composed of a central open courtyard surrounded by four iwans in the pattern known for madrasa, as it also contains four madrasas for the four “mazhabs” placed at the corners of the building with entrances through the courtyard, in addition to a mausoleum and a kuttab and a group of services, utilities and a medical unit, as shown in Fig. (5-17).

The four madrasas were assigned to teach the four “mazhab”, interpretation of Qur’an (Tafsir), the Prophet’s tradition (Hadith) and the seven recital methods. The madrasas have similar designs as a whole, consisting of a small open courtyard with an octagonal fountain at its centre. Each of the madrasas contains doors leading to vaulted recesses containing niches, windows and cells for the students overlooking the courtyard through six rows of windows. The ablutaries were placed in a central area in each madrasa in the ground floor adjacent to the stairs.

Figure 5-17: The composition of masses in Madrasa of Sultan Hassan

b- The Plan

The four iwan arrangement of the madrasa takes up the centre of the plan, with an ablutions fountain in the centre of the courtyard and the four madrasas accommodated in the corners of the plan. The qibla iwan is significantly larger than the remaining three, which are also monumental in size and scale, as shown in Fig. (5-18). Rather than integrating the students' cells into the central space, the cells were arranged along the street facades and their windows comprise an integral part of the architecture of the facades.

The four monumental iwans fully dominate the courtyard of the mosque, with no living units to share the inner space. Unlike previous madrasas, where living units overlook the courtyard, the residential space here is totally separate from that of the public Friday mosque. This separation may be related to the double function of the complex, as a madrasa dedicated to the academic community and a Friday mosque accessible to the general public.

The four madrasa wings have no direct communication between them, but only through the courtyard. Only the Maliki Madrasa can be accessed directly from the entrance. A corridor, which connects the entrance vestibule with the Maliki Madrasa and further to the courtyard, turns around the west iwan, branching off to the ablution area, and bends back to the courtyard without giving access to the Hanbali wing. Each of the four wings of the madrasa has its own courtyard with study cells on three sides and a vaulted iwan on the qibla side and the living units are accommodated in the floor above.

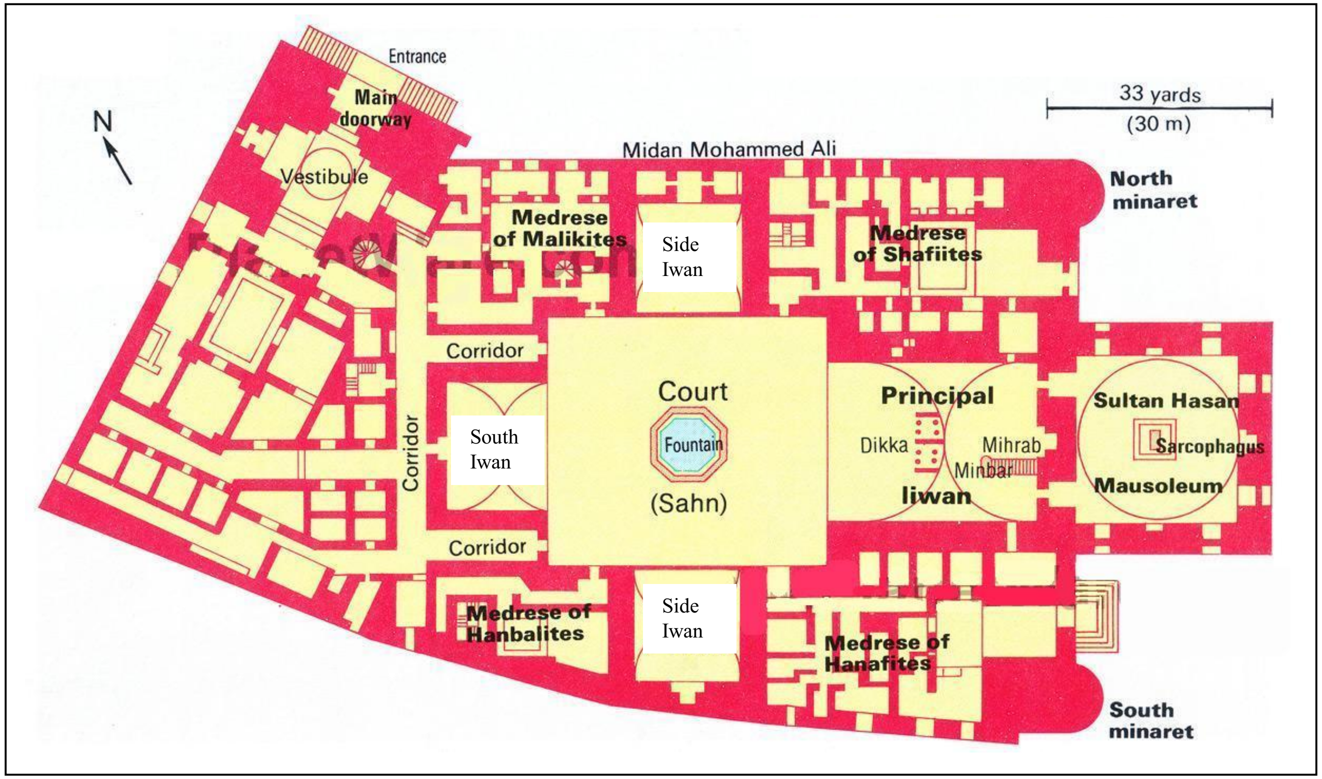


Figure 5-18: The plan of Madrasa of Sultan Hassan

c- The Facades

The gigantic portal of Sultan Hasan, c.38 m high, is visible from Rumayla Square and the Citadel due to its projection and its askew position in relation to the rest of the facade, as shown in Fig. (5-20).

The muqarnas-hood portal occupies the entire length of the facade. The portal design consists of a magnificent rectangular arabesque-carved frame doubled by another external frame of interlocking bands framing carved rectangles.

The facades are mainly comprised of rectangular niches that have the full height of the building confirming the vertical direction in the design, although the internal formation of the rectangular niches differed according to the variation of the plan's elements, which reflects the organic relationship of the facade with the plan. The height of the exterior walls and the arrangement of the windows give the facades a strongly vertical emphasis.

Both the southern and northern facades are characterized by their extraordinary fenestration. Six recesses pierced with eight vertical rows of windows correspond to four stories of cells each with two superimposed windows, as shown in Fig. (5-19). This configuration, which gives the facades a contemporary look, was a further outstanding feature, which added a new dimension to the art of fenestration in Mamluk architecture. However, it was not to be repeated elsewhere. Both facades have an oculus set in a recess above two superimposed windows, corresponding to the middle of the northern and southern iwans. The northern and main facade is 150m long.

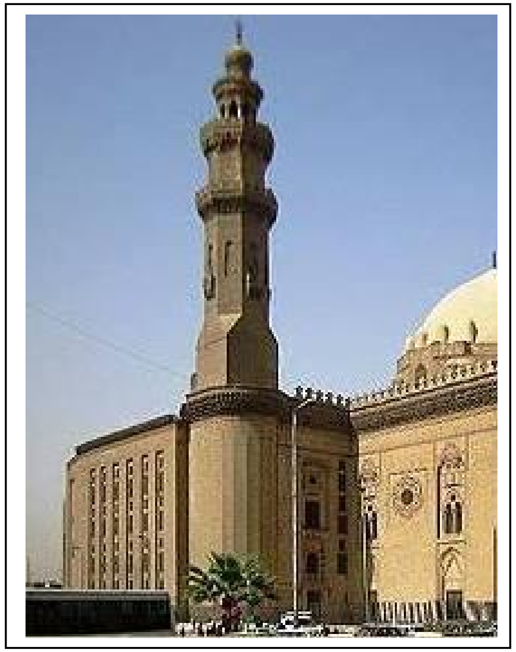


Figure 5-19: The fenestration system in Madrasa of Sultan Hassan

Figure 5-20: The position of the entrance in Madrasa of Sultan Hasan

d- The Minarets

The madrasa used to contain 2 pairs of minarets one on both sides of the mausoleum and the other on either side of the portal. The southeast facade has two similar minarets although the southern one is higher than the eastern and at the bottom end of its top there is a pavilion. In the first octagonal shaft of the two minarets there are arched recesses flanked by a columns and preceding four of these recesses are stone balconies, as shown in Fig. (5-21).

e- The Mausoleum

The mausoleum is located behind the qibla wall of the mosque covering a square area. The mausoleum is distinguished for its location on an axis with the building in front of the qibla iwan overlooking the main square in front of the citadel; the tomb was built for the burial of Sultan Hasan and it is covered with by a huge dome. It is interesting to note that the positioning of the mausoleum between two minarets was a further novelty, adding a new dimension to the Cairene art of juxtaposing the dome and the minaret, as shown in Fig. (5-22).

The position of the mausoleum in relation to the sanctuary is unique in Mamluk architecture. Placed behind the prayer hall, occupying the same width, one would think that it must have breached some unwrittcn law against the building of a profane mausoleum in the direction of prayer.

Although the mausoleum is free-standing on three sides, the architect did not use the space available to increase the number of windows and add light to the funerary chamber, which remains, perhaps deliberately, rather dark. Each of the three facades displays two pairs of windows and a central oculus. All three oculi are framed by inlaid rosettes of interlace petals in ablaq masonry. The same kind of interlace frames the conchs of the upper window recesses, as shown in Fig. (5-22).

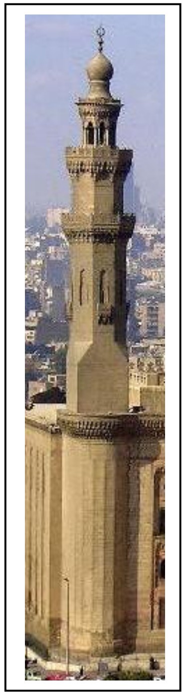


Figure 5-21: The minaret composition in Madrasa of Sultan Hassan

Figure 5-22: The position of the mausoleum in Madrasa of Sultan Hassan

3- Applying the Geometric Generative Technique: (Technique Steps)

The technique steps are applied to generate the building space design.

Pre-Design Step:

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building's entrance so that it is in relation to the entrance of the citadel, which is in confrontation to the building, so it turns towards the Citadel at an angle of 17° from the facade to reveal its grandeur and novelty, as shown in Fig. (5-24).

b- Study the position of the dome

The designer chooses the position of the building's dome to be in direct relation with the street, as shown in Fig. (5-23).

c- Study the position of the minaret

The designer chooses the position of the minaret to play the role of landmark for the site and so the pedestrians can see it from a distance, as shown in Fig. (5-25).

Figure 5-23: The position of the dome in Madrasa of Sultan Hassan

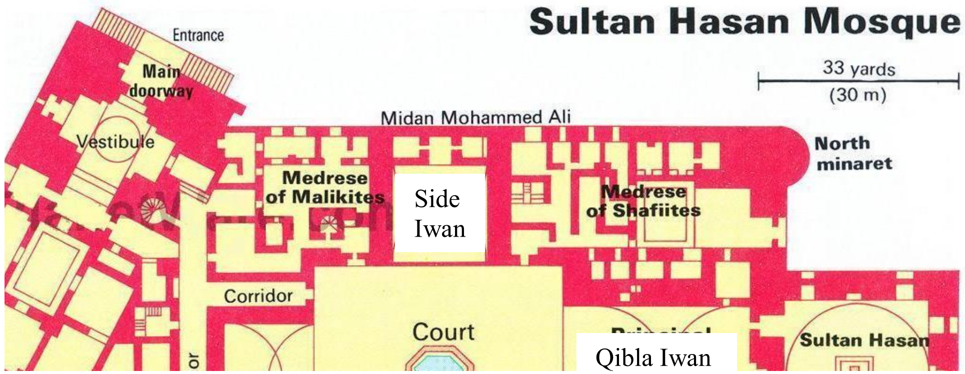


Figure 5-24: The position of the entrance in Madrasa of Sultan Hassan

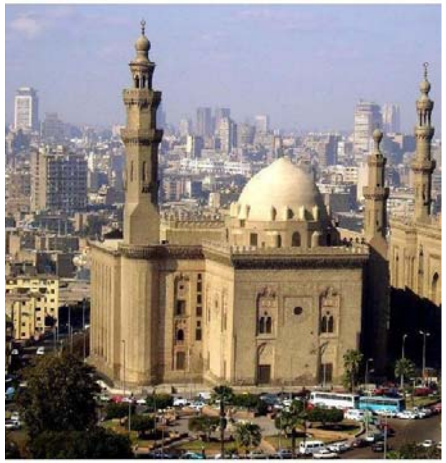


Figure 5-25: The view of the minaret from the street in Madrasa of Sultan Hassan

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Figure (5-26).

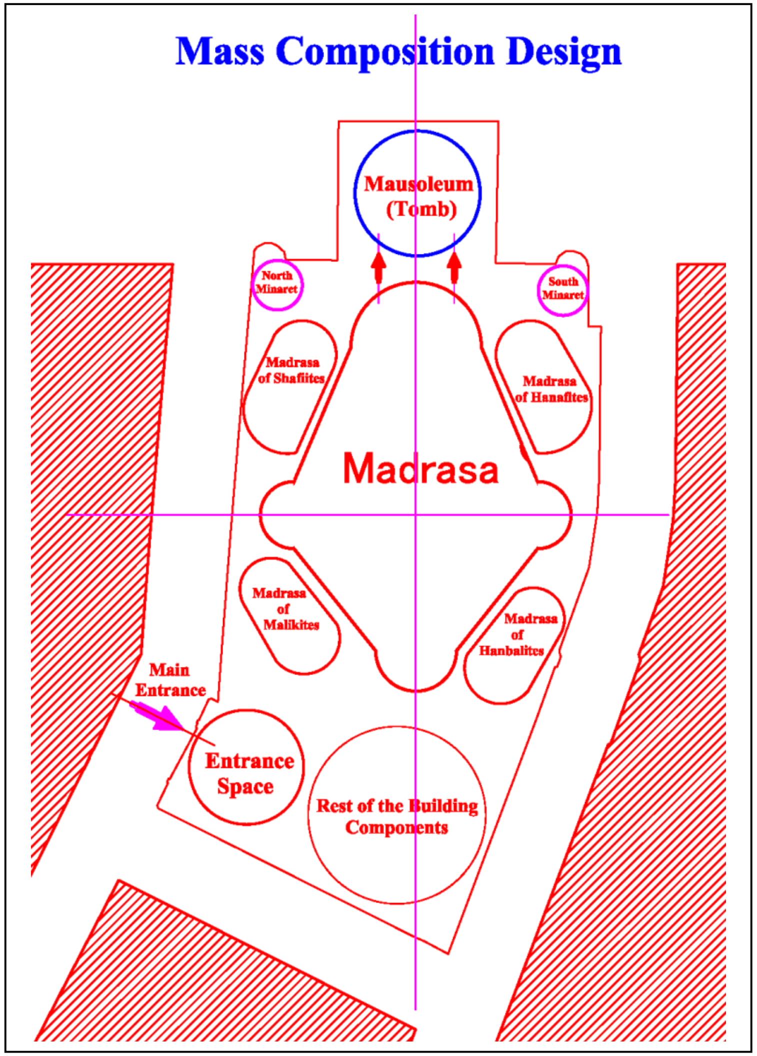
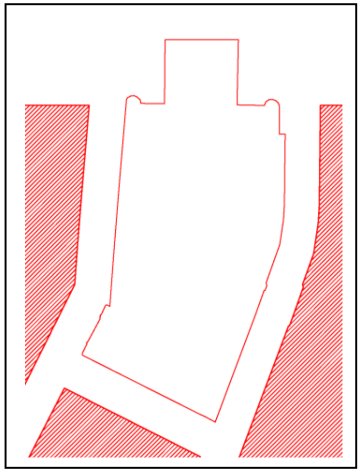
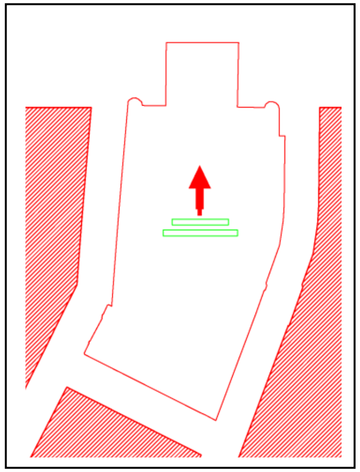


Figure 5-26: The mass composition in Madrasa of Sultan Hassan

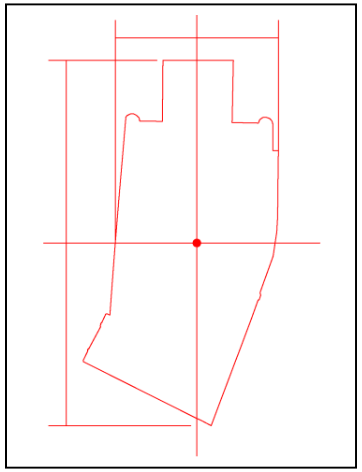
<u>1- First Step:</u> Determining the Site boundary, the Qibla Direction and the Sahn's Centre point.



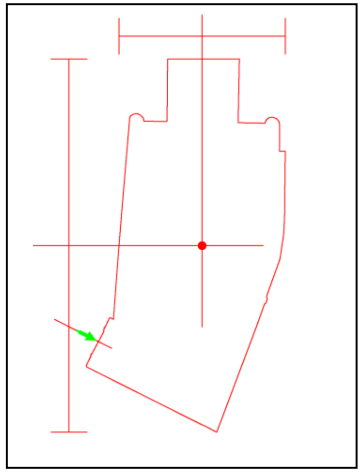
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

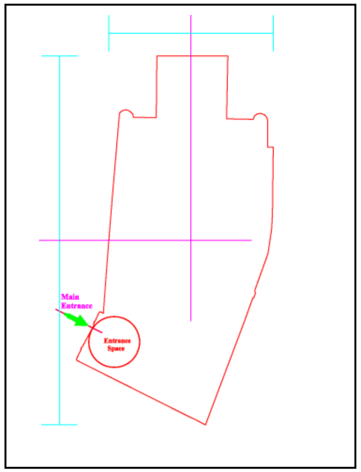


c- Determining the sahn's centre point

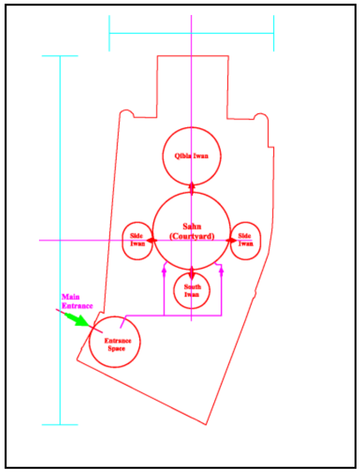


d- Adding the main entrance axis

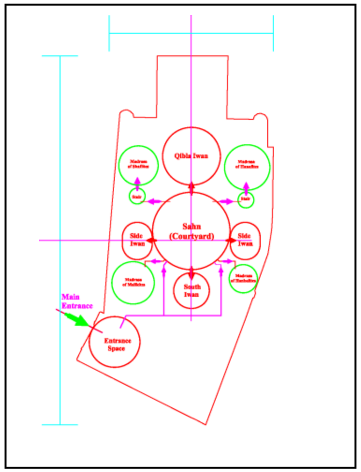
<u>2- Second Step:</u> Determining the Functions' Relationships and the Users' Circulations Diagram.



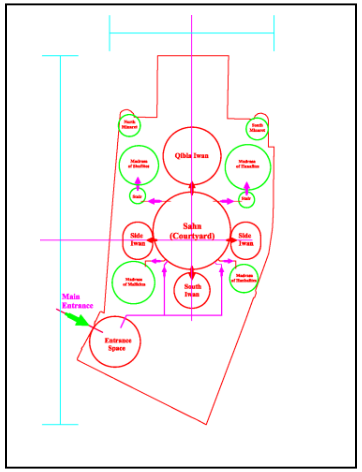
a- Determining the entrance spaces according to the



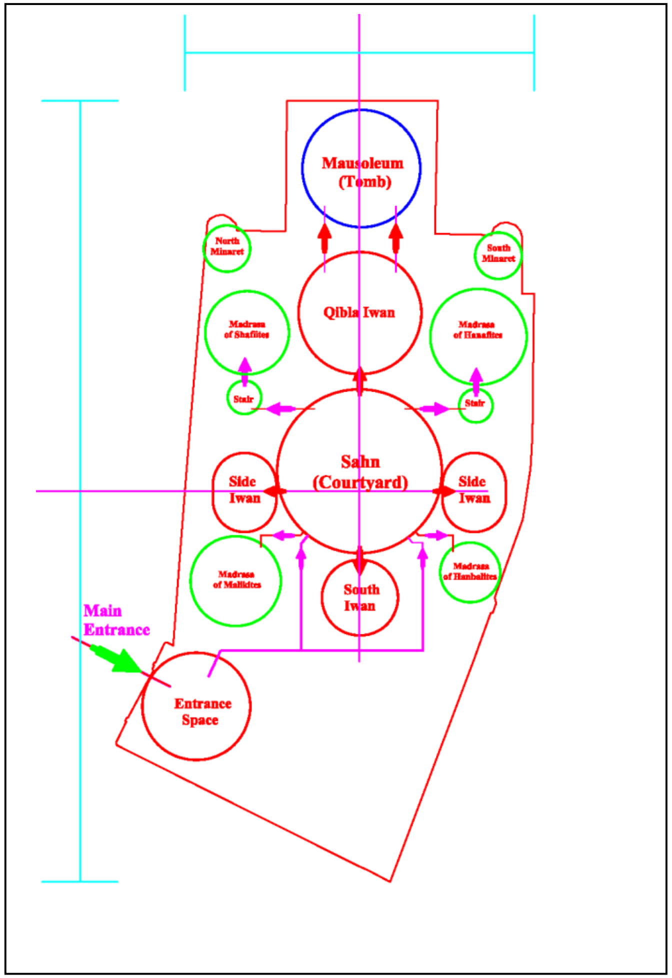
b- Determining position of the sahn and all iwans



c- Determining the four teaching schools position

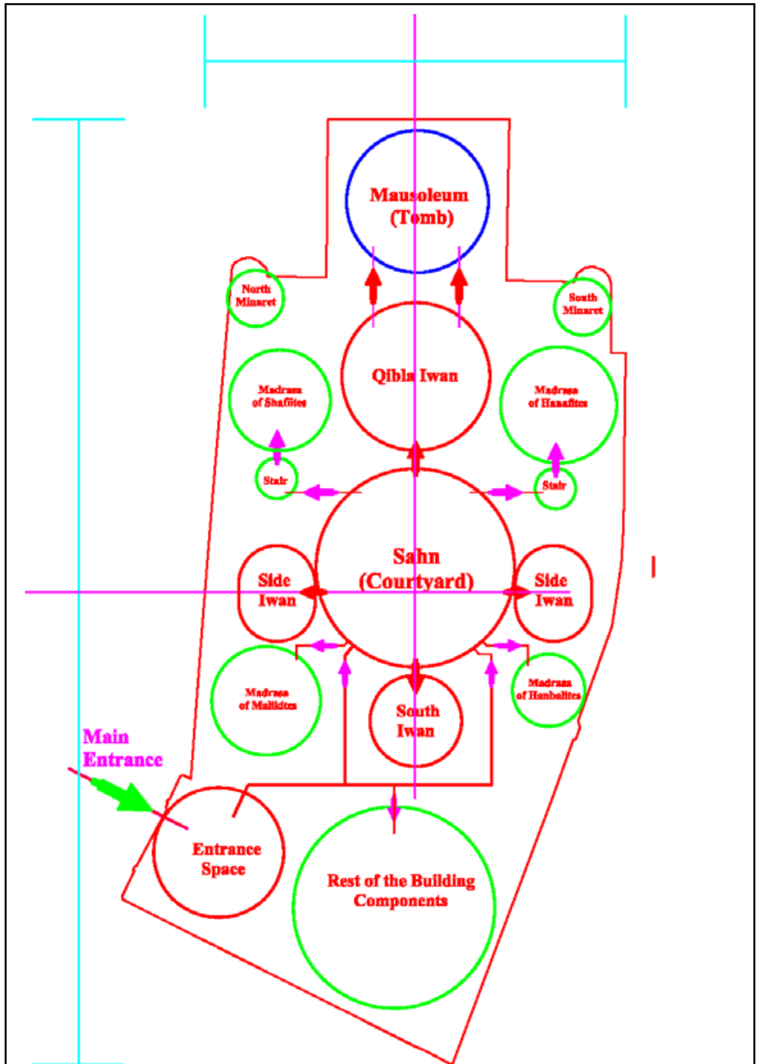


d- Determining the minaret position



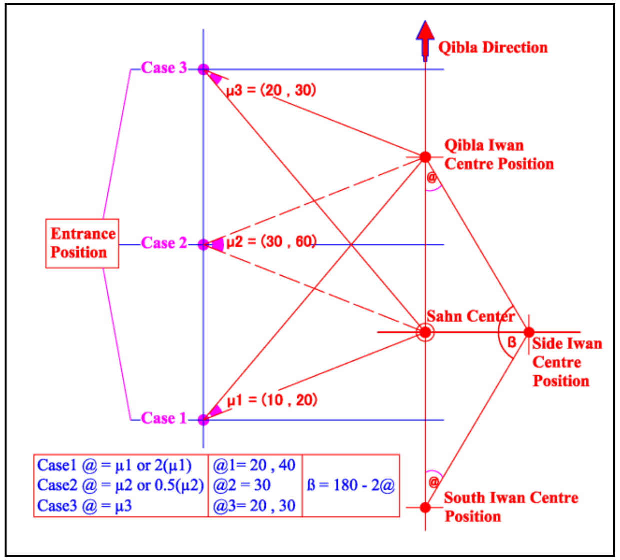
e- Determining the mausoleum position

Figure 5-28: The final functions' relationships diagram in Madrasa of Sultan Hassan

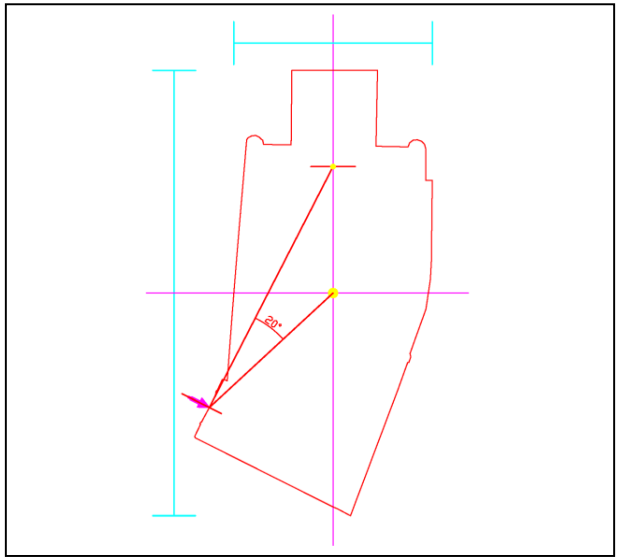


Functions' Relationships and Users' Circulations Diagram

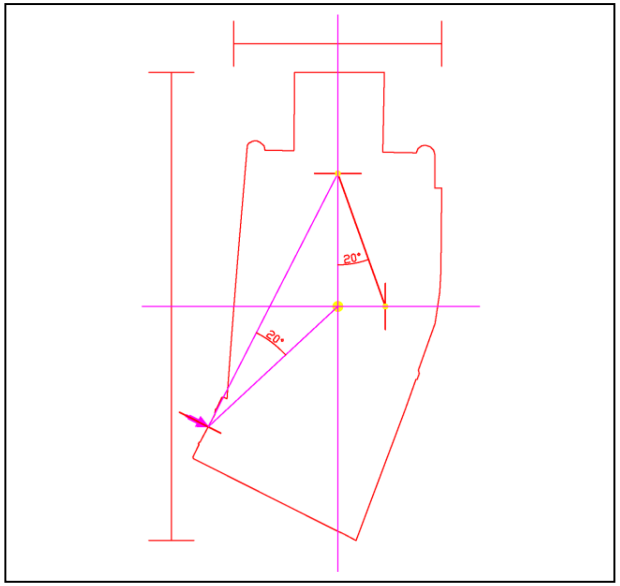
<u>3- Third Step:</u> Applying the Hidden Geometric System (Determining **µ**, **@** and **ß** angles)**.**



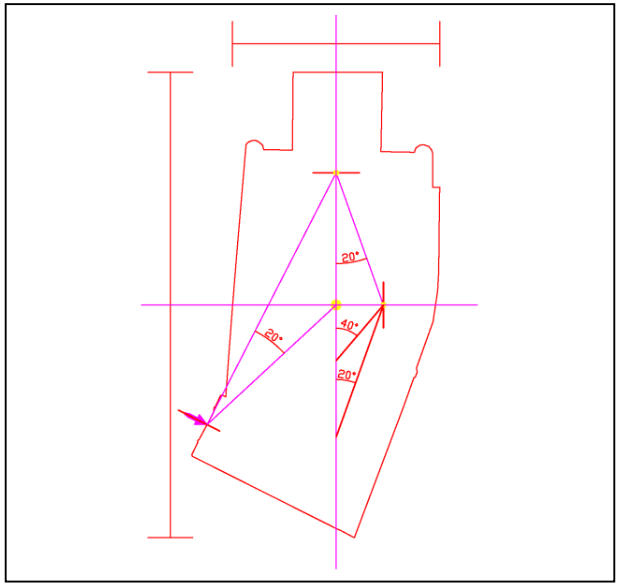
a- The hidden geometric system



b- Determining the qibla iwan's centre point



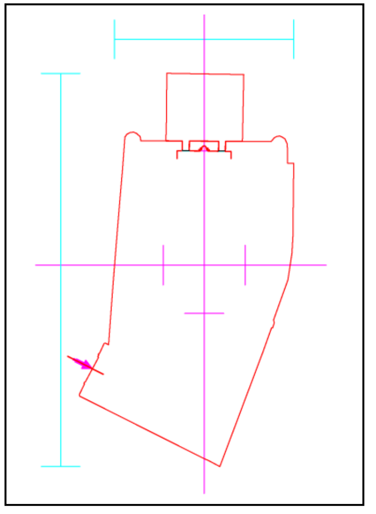
c- Determining the side iwan's centre points.



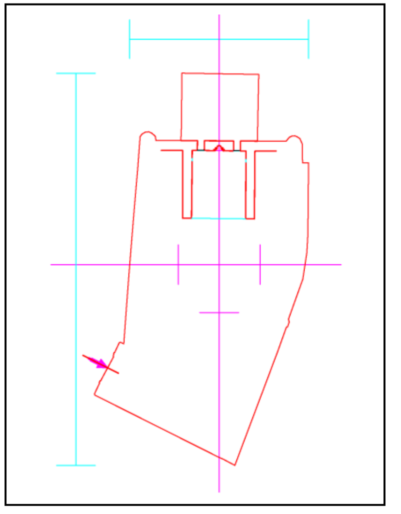
d- Determining the south iwan's centre point

4- Fourth Step: **Generating the building plan's design (The Design of the building in 2D).**

1- Generating the Qibla Iwan (Praying Hall)

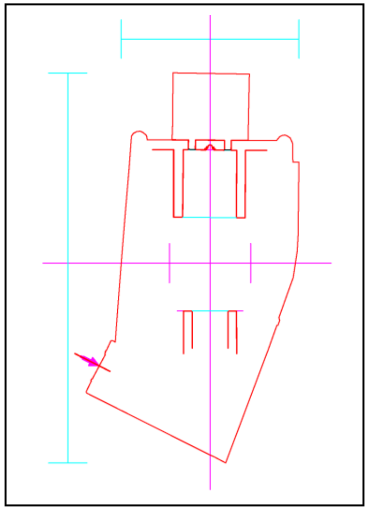


a- Designing the qibla wall

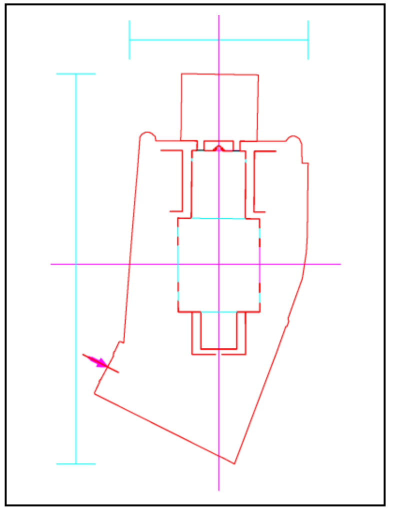


b- Completing the design of qibla iwan

2- Generating the South Iwan

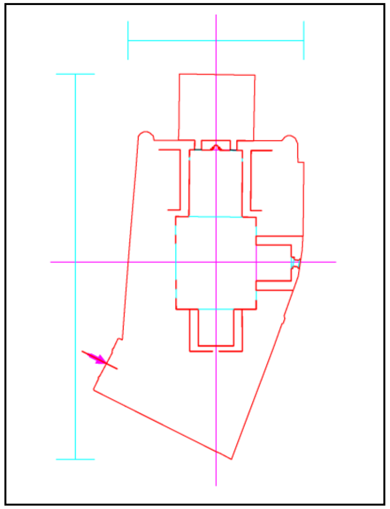


a- Beginning with the width of the iwan

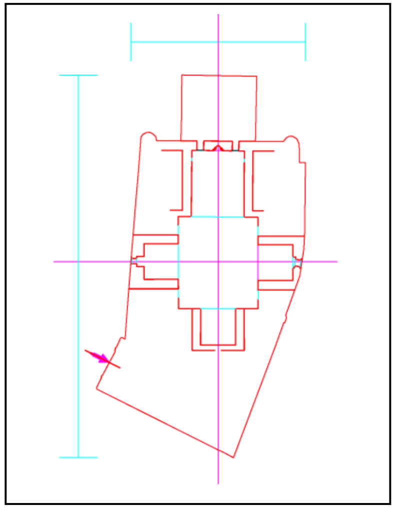


b- Completing the south iwan design

3- Generating the Sahn (Courtyard) and the Two Side Iwans



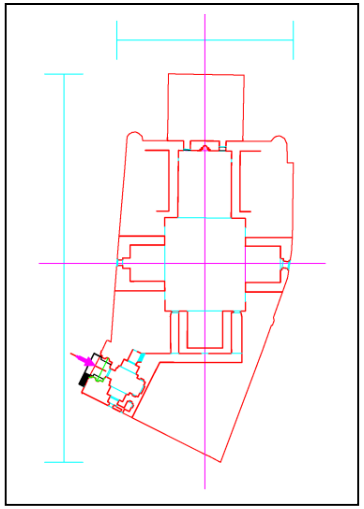
a- Designing one of the side iwans



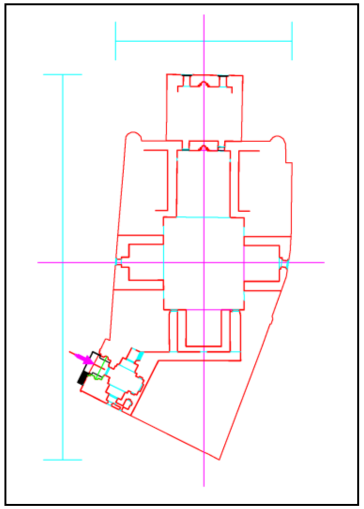
b- Designing the second side iwan

4- Adding the Entrance Design

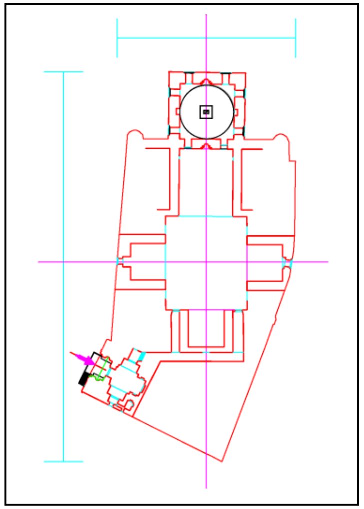
a- Adding the entrance components spaces,
b- Designing the path from the entrance to the sahn.
c- Adding the entrance cells.



5- Generating the Mausoleum

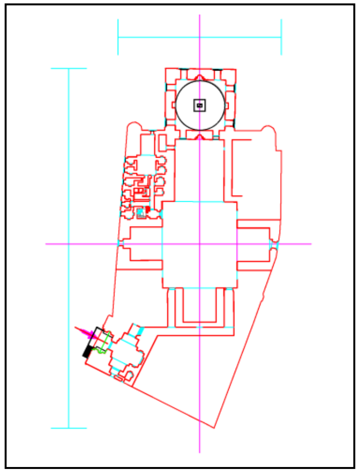


a- Designing the qibla wall inside the mausoleum

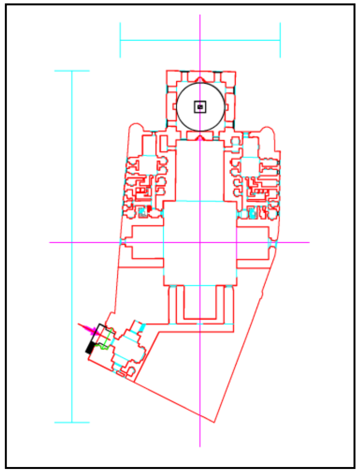


b- Completing the mausoleum main space

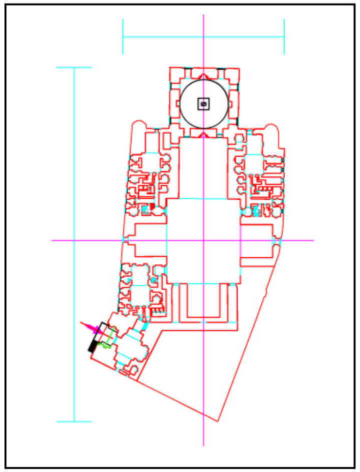
6- Designing the Four Teaching Schools “Mazahib”



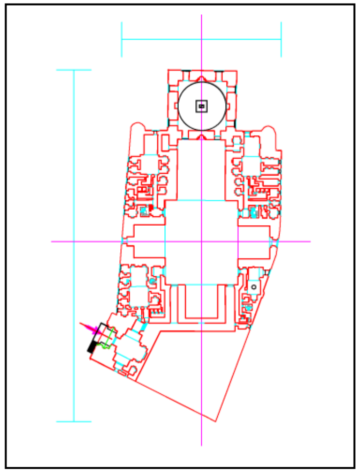
a- Designing the Madrasa of Shafiites



b- Designing the Madrasa of Hanafites

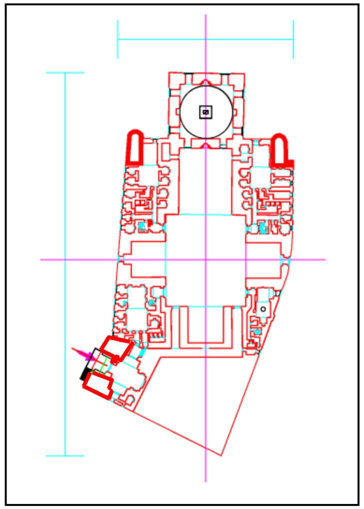


c- Designing the Madrasa of Malikites

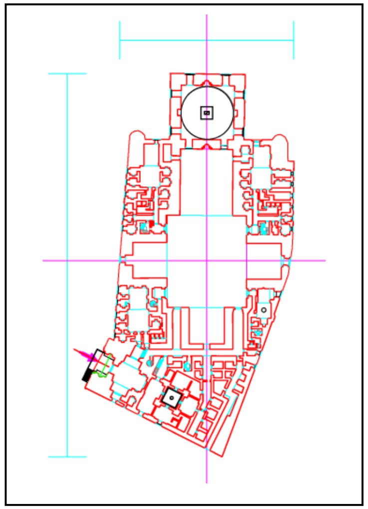


d- Designing the Madrasa of Hanbalites

7- Adding the Minarets



8- Completing the Rest of the Building’s Service Spaces



9- The Final Building Plan with the H.G.D. System

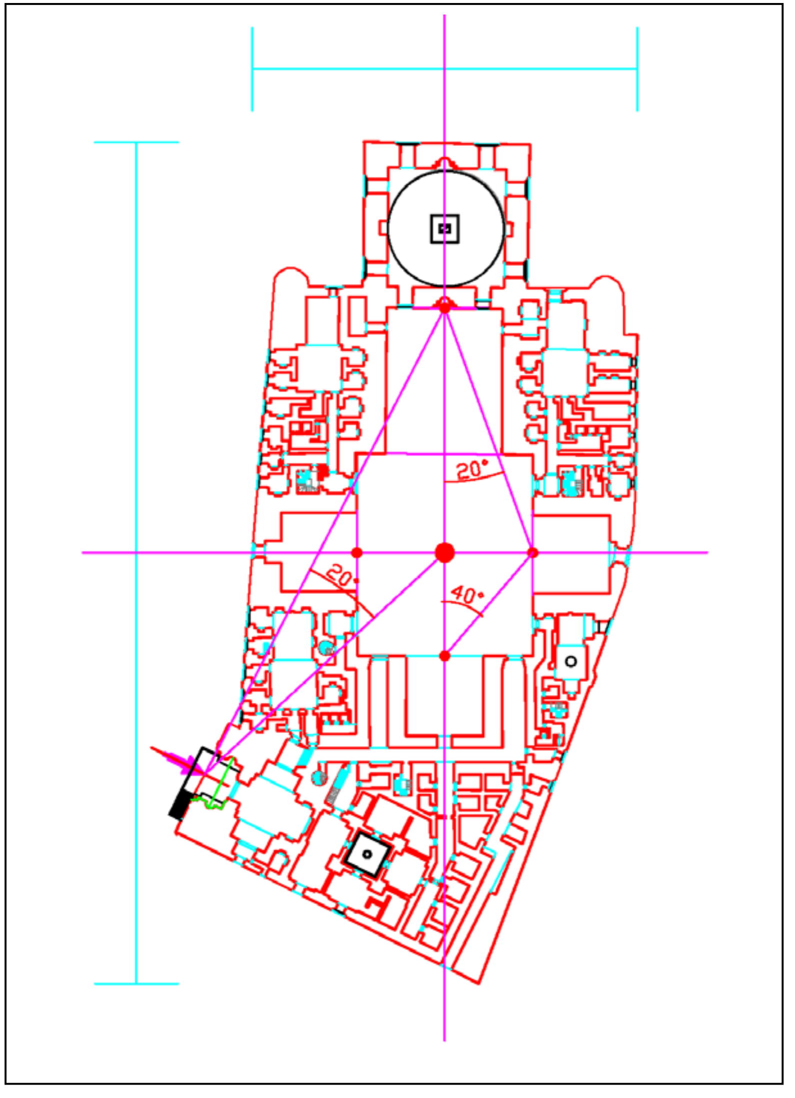


Figure 5-29: The final plan of Madrasa of Sultan Hassan with the hidden geometric design system.

10- Generating the Final Building Plan

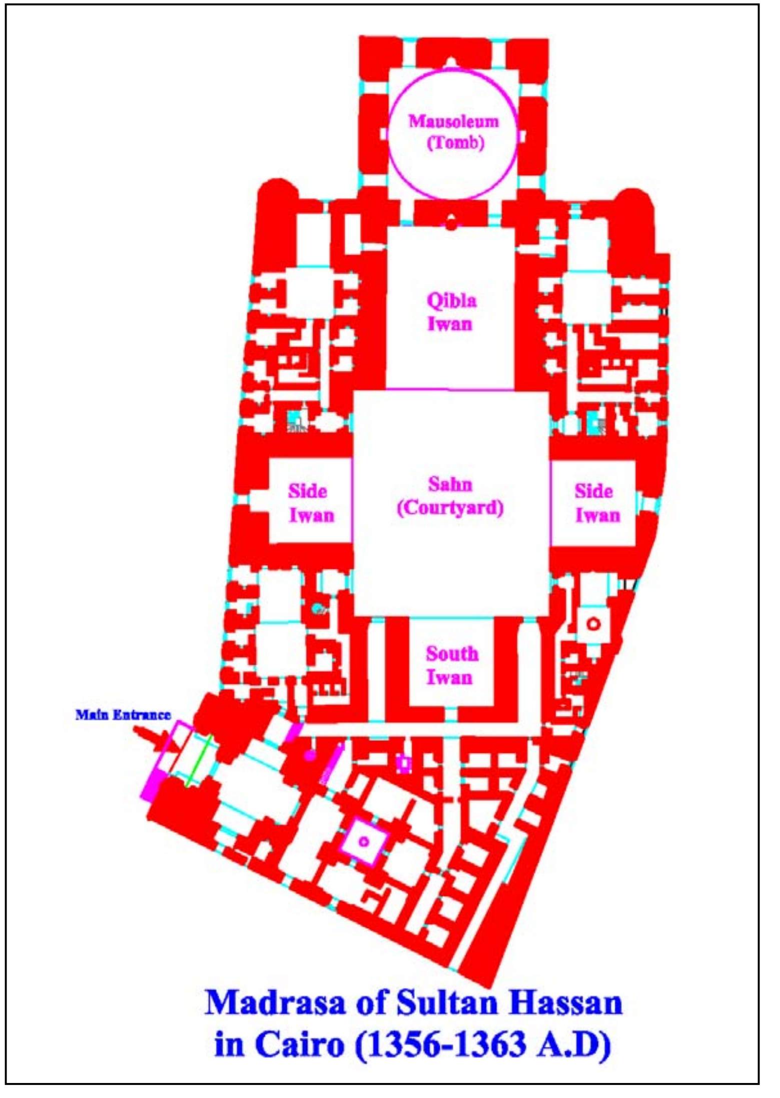


Figure 5-30: The final plan of Madrasa of Sultan Hassan Hasan

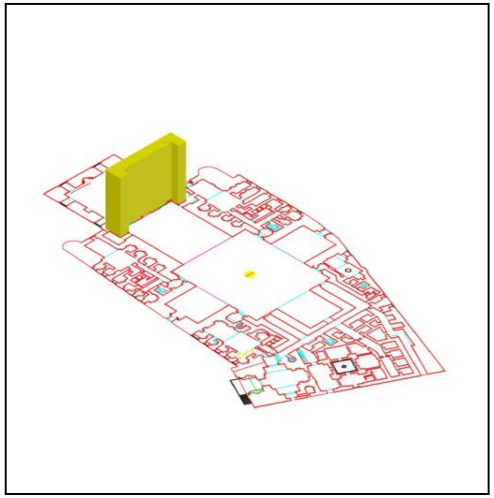
<u>5- Fifth Step :-</u> Applying the Interior Space Design Rules.

These are the results of applying the interior space design rules in the Madrasa of Sultan Hassan:
* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.
* The entrance spaces are roofed and their height is equal to the building's total height.
* The mausoleum is covered with a dome.
* The design follows the opened courtyard type.

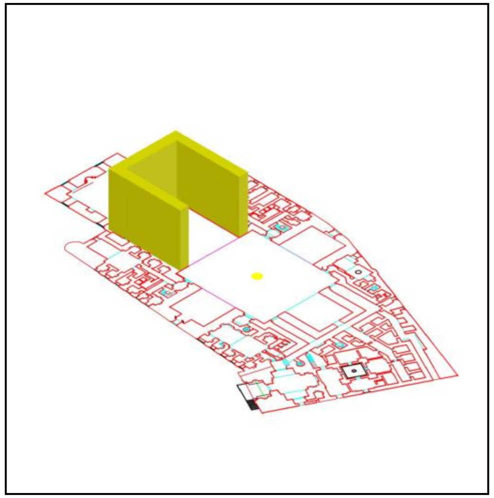
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans which he has designed into three-dimensional spaces.

6- Sixth Step: Generating the Building Spaces' disposition (The Design of the building in 3D).

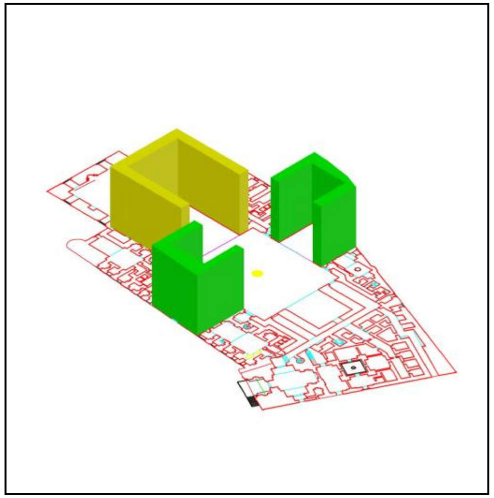
1- Constructing the Qibla Wall



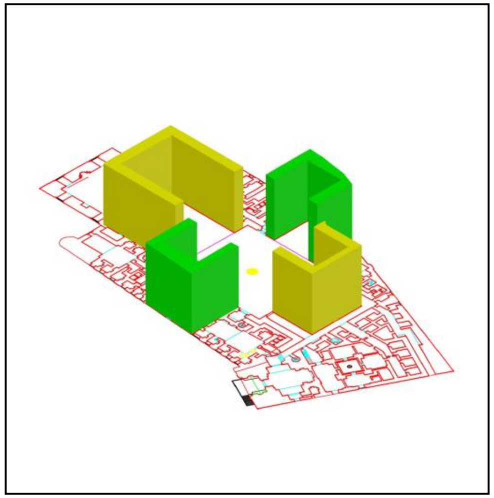
2- Completing the Qibla Iwan



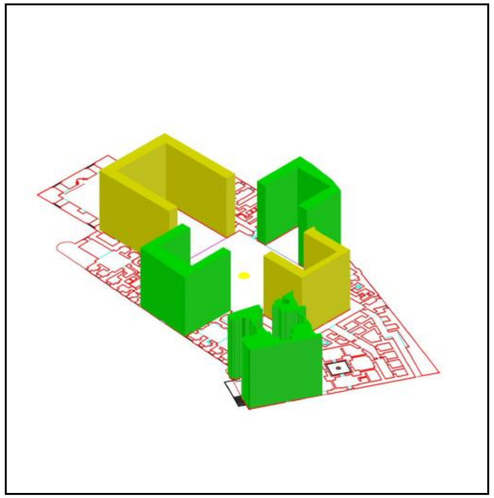
3- Constructing the Side Iwans



4- Constructing the South Iwan

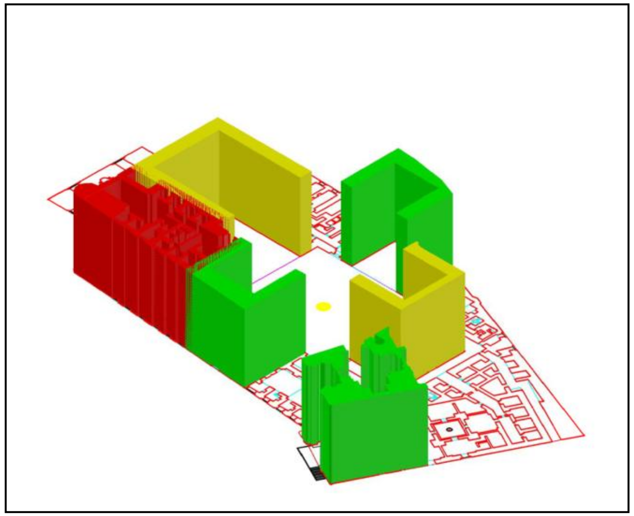


5- Constructing the Entrance and its Spaces

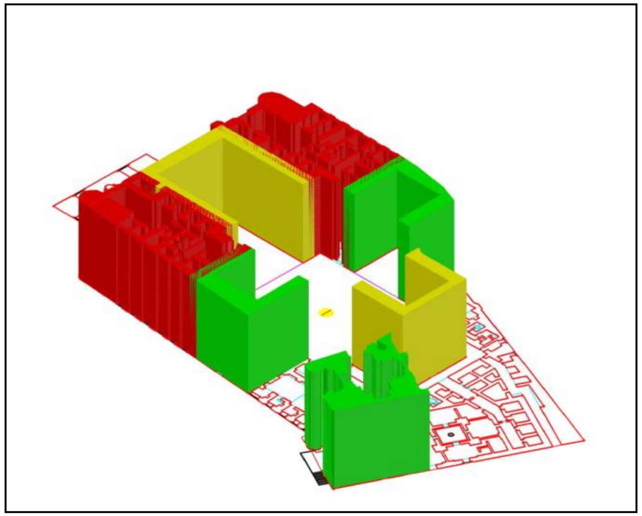


6- Constructing the Four Teaching Schools "Mazahib"

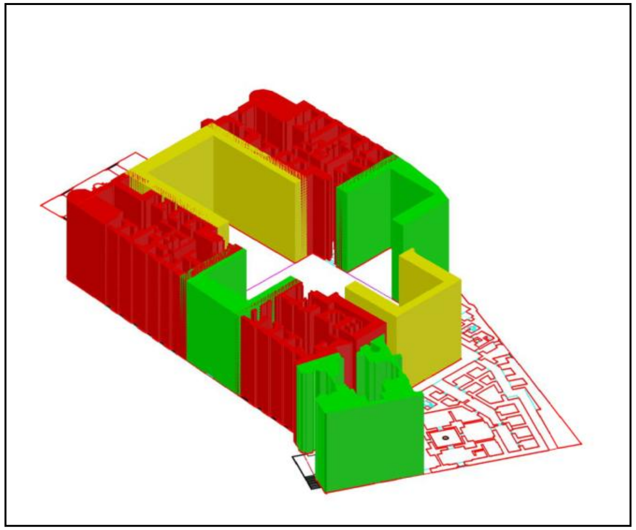
a- Constructing the Madrasa of Shafiites



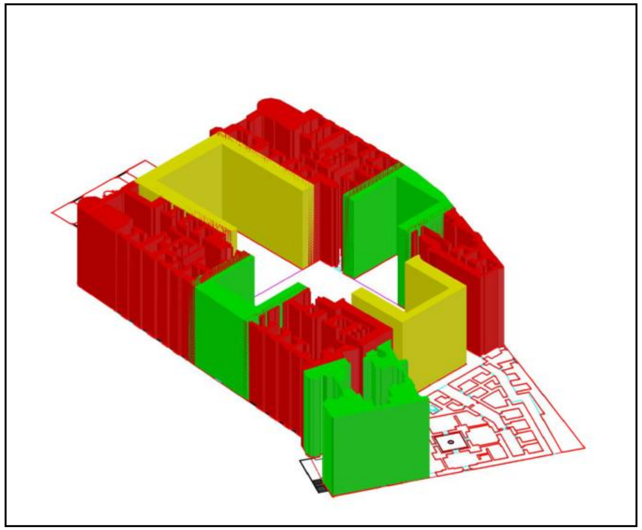
b- Constructing the Madrasa of Hanafites



c- Constructing the Madrasa of Malikites

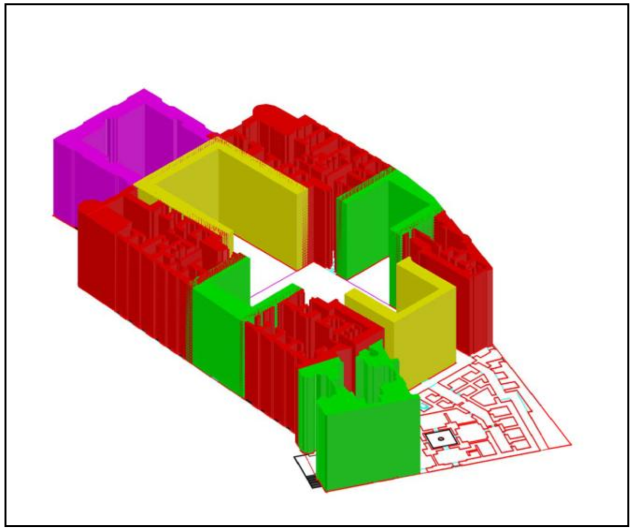


d- Constructing the Madrasa of Hanbalites

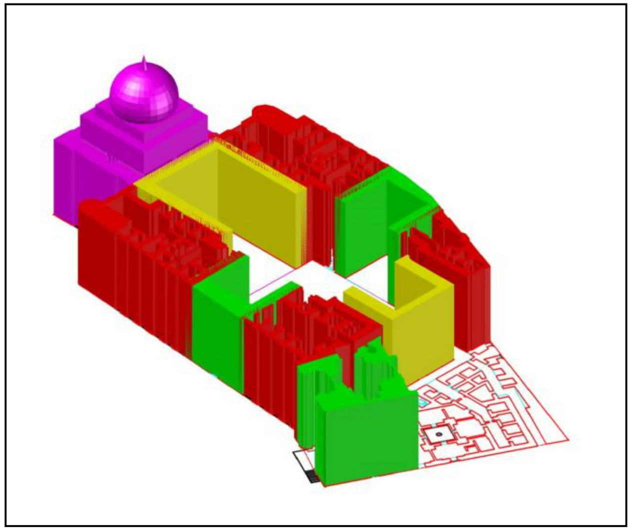


7- Constructing the Mausoleum

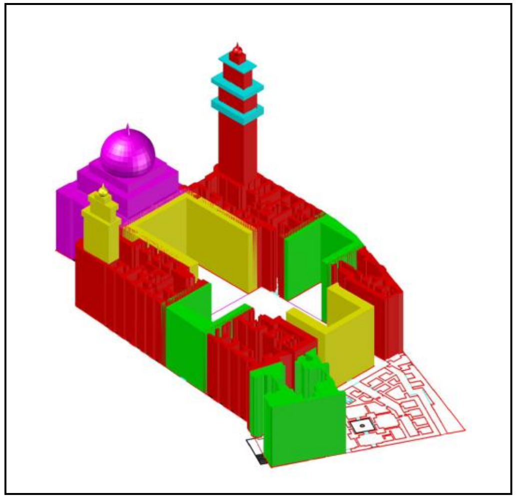
a- Constructing the Mausoleum Walls



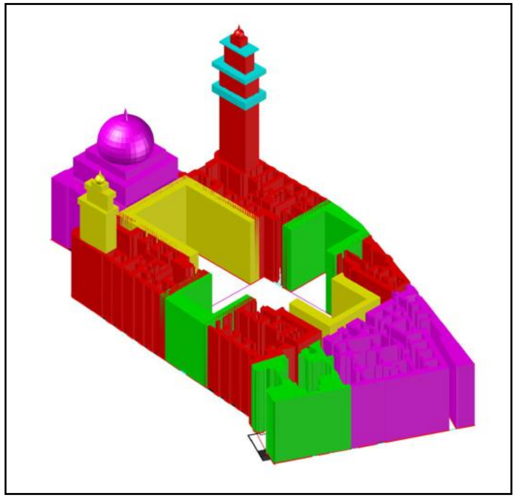
b- Roofing the Mausoleum (constructing the dome)



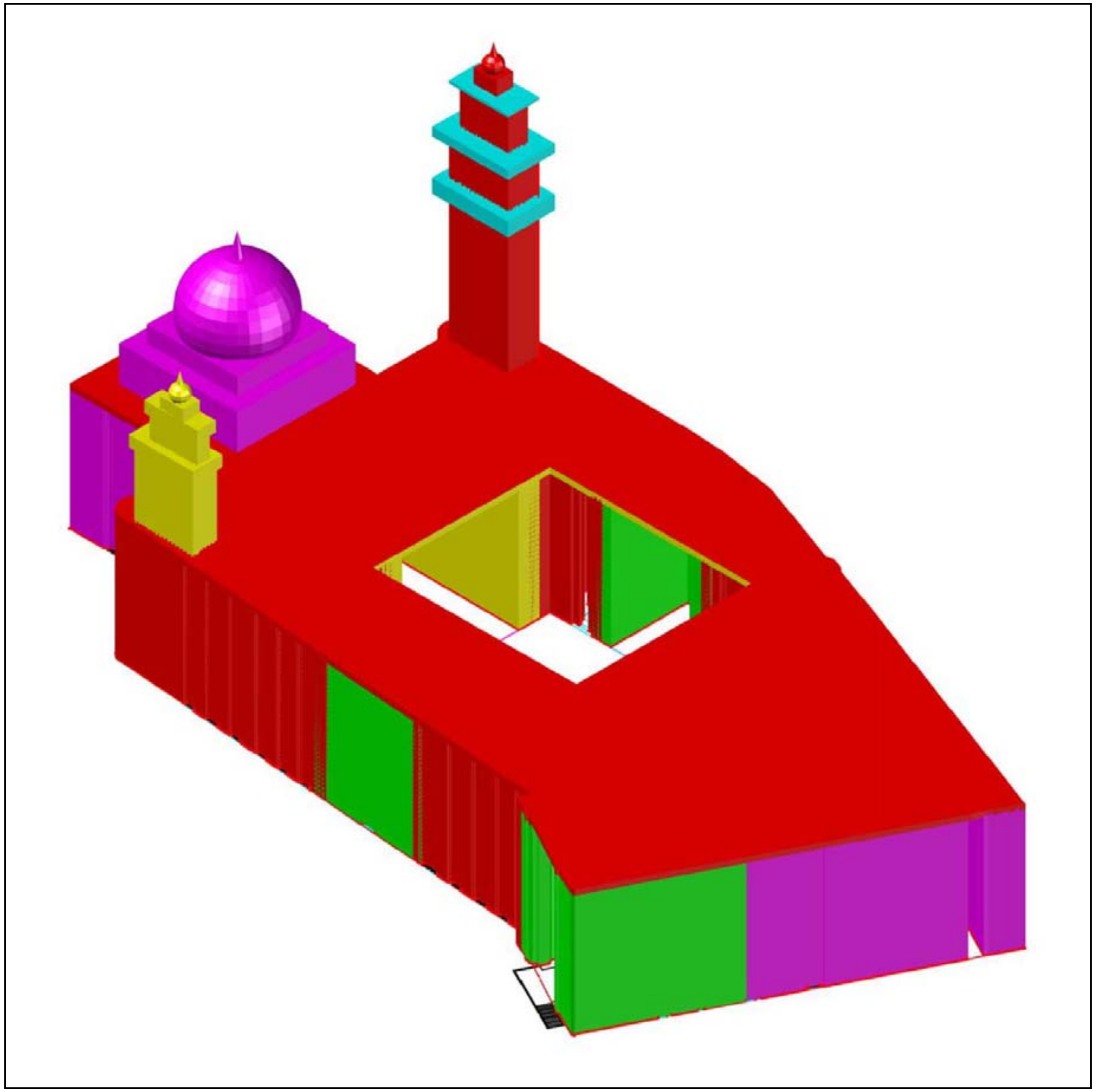
8- Constructing the Minarets



9- Constructing the Rest of the Building's Spaces



10- Roofing the Building



5.2.1.3 Madrasa of Umm al-Sultan Sha‘ban (1368-9 A.D.)

1- General Description:

The madrasa was built by Sultan al-Ashraf Sha'ban in 1368-9 A.D. and dedicated to his mother Khawand Baraka. The madrasa is located in Bab al-Wazir Street on the right side heading towards the mountain citadel. This madrasa is the first religious structure in Cairo to revert, after a lapse of centuries, to the rather easterly Makkah orientation or qiblat al-sahaba, as opposed to the one favoured in Mamluk times. This adjustment of the divergence between the qibla orientation and the main street proved to be very advantageous to the configuration of the building, both inside and out. It allowed the architect to bend the qibla facade with the two-domed mausoleum towards the main street, thus ensuring higher visibility [(OICC),1992]p.132.

Variant Names	* Madrasa of Umm al-Sultan Sha‘ban, * Mosque and Madrasa of Umm al Sultan Sha'ban ('Umm as-Sultan Shaban), * Mosque, Madrasa and Mausoleum of Khawand Baraka (Khwand Baraka)
Street Address	Bab al-Wazir Street, Tabbana Quarter
Location	Cairo, Egypt
Date	14th (1368-1369 A.D.)
Style/Period	Mamluk (Bahri)
Building Types	Complex (Educational, Funerary)
Building Usage	Madrasa, Mausoleum, Sabil.

Table 5-3 The General Description of Madrasa of Umm al-Sultan Sha’ban

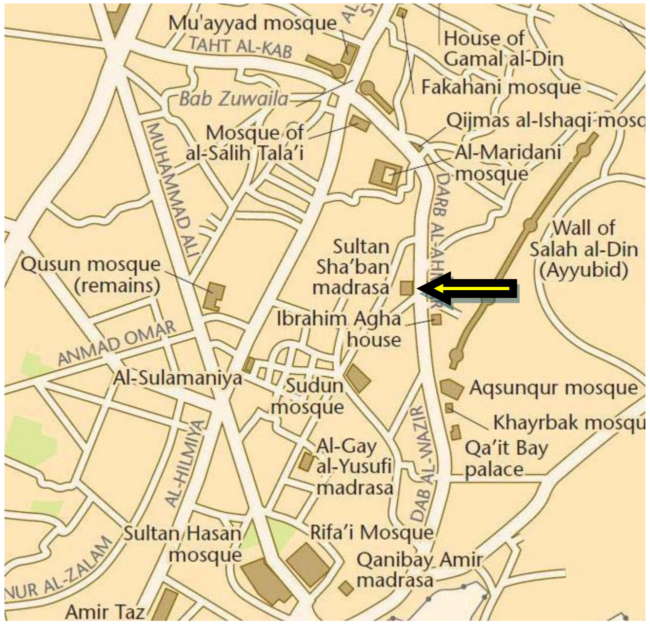


Figure 5-31: The site of Um Sultan Sha’ban Madrasa

2- Architectural Description

The madrasa consists of a central open courtyard, with four iwans perpendicular to it, the largest of which is the qibla iwan. The madrasa also contains halls for teaching and rooms for scholars on the upper floor; it also contains a kuttab for teaching orphans and a water basin for animals.

Upon analysis, the complete integration of the external formation with the internal one is noted, and each architectural element is expressed clearly on the facade so that they can be felt immediately from the facade, reflecting the organic functional relationship between them.

a- The Layout

In general, it is noted that the madrasa's block has been formed according to the street line and the surrounding urban fabric, as the minaret was placed at the edge of the facade next to the tomb's dome in the southeast corner of the building. Its position is at the meeting point of the main road connecting Bab Zuwayla and the citadel, also, to produce a kind of balanced feeling over the different blocks of the building.

b- The Plan

The internal madrasa plan houses four iwans, although it was only built to teach two school of jurisprudence, the Hanafi and the Shafi'i.

In the plan, the connection between the relevant elements is clear either vertically or horizontally, as shown in Fig. (5-32) as the rooms of the students on the upper floor are vertical on the principal iwans with entrances from the courtyard. Also the two tombs are directly connected to the entrances, as well as the sabil (water fountain for drinking) which was suitably located to facilitate use of the water source.

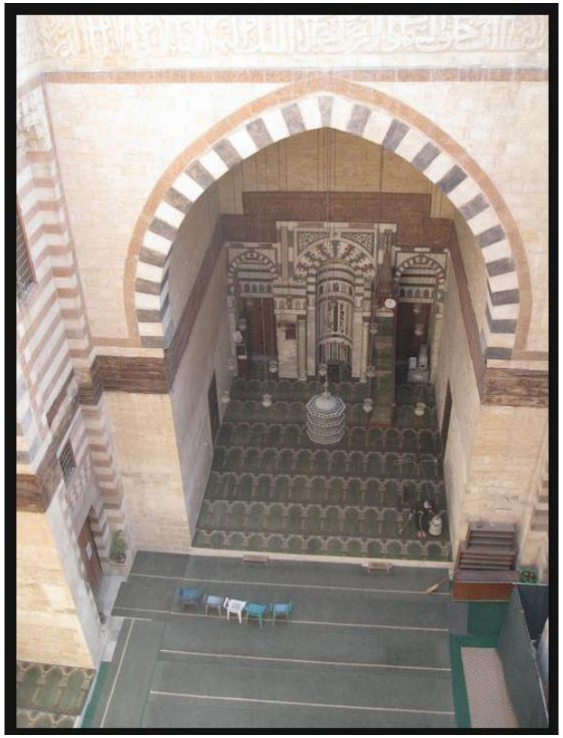


Figure 5-32: The sahn and qibla iwan in Madrasa of Um Sultan Sha'ban

c- The Facades

The muqarnas-hood portal occupies the entire length of the facade. The height of the exterior walls and the arrangement of the windows give the facades a strongly vertical emphasis, as shown in Fig. (5-33).

The main feature of the facade is the beautiful entrance, which stands in a recess covered by a tier of distinctive Anatolian muqarnas portals.

It is noted that there are multiple entrances; this may be attributed to the fact that the madrasa overlooked three streets. The madrasa has two entrances one open at the northern corner of the southeast facade on the left of the animal water basin, which is the main entrance. The second entrance opens on the southeast facade. The main entrance leads to the courtyard across a bent entrance and a corridor, and then the secondary entrance leads directly to the courtyard across the vestibule. The location of the main entrance has been articulated on the facade by placing it on a high rectangular niche whose hood and spandrels are formed with carved stone ornaments. The entrance, as such, inspires a feeling of awe upon entering, and when moving gradually to the internal space across the vestibule to enter into the prayer and study space, thus gradually separating the person from the outside environment. The secondary entrance had no particular architectural treatments, but comes in with the alignment.

Figure 5-33: The main facade in Madrasa of Um Sultan Sha'ban

d- The Minaret

The minaret in the corner of a facade wall, instead of the typical spots on the vault or corners of a monumental portal, is unusual. The madrasa has a minaret in the shape of an octagonal shaft with eight recesses crowned by a pointed arch opened on four sides of which are bays are preceded by crenellations. The shaft is topped by a balcony supported by stalactites and surrounding a smaller octagonal shaft decorated with horizontal moldings crowned on the top rows of stalactites, as shown in Fig. (5-35).

e- The Mausoleum

The qibla iwan is flanked by two tombs chambers with lofty domes: from the northeast side, by the tomb of al-Sultan Sha'ban, and from the southeast side by the tomb of Umm al-Sultan. The large tomb chamber on the left is where Khwand Baraka and one of her daughters are buried. In front is an irregularly shaped room that was probably used for storing large Qur'ans or for special Qur'an recitations. The smaller tomb on the right, with no decoration and no mihrab, is the final resting place of Sultan Sha'ban and his son al-Mansur Hajji, as shown in Fig. (5-34). There is no Qur'anic Law requiring the separate burial of men and women.

Figure 5-35: The dome and the minaret in Madrasa of Um Sultan Sha'ban

Figure 5-34: The mausoleum dome and the minaret in Madrasa of Um Sultan Sha'ban

Pre-Design step:

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building's entrance in the main street making a lobby in the street.

b- Study the position of the minaret

The designer chooses the position of the building's minaret so that it plays the role of the landmark to the site and pedestrians can see it from a distance, as shown in Fig (5-36).

c- Study the position of the dome

The designer chooses the position of the building's dome so that it is in relation to streets which surrounding the building, as shown in Fig. (5-37).

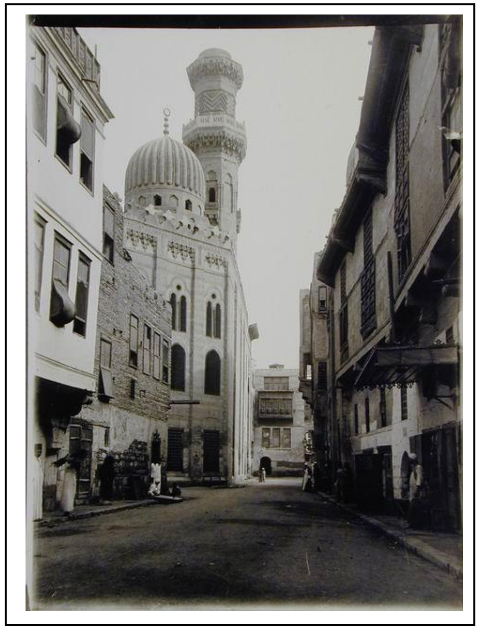


Figure 5-36: The view of the minaret from the two sides of the street in Madrasa of Um Sultan Sha'ban

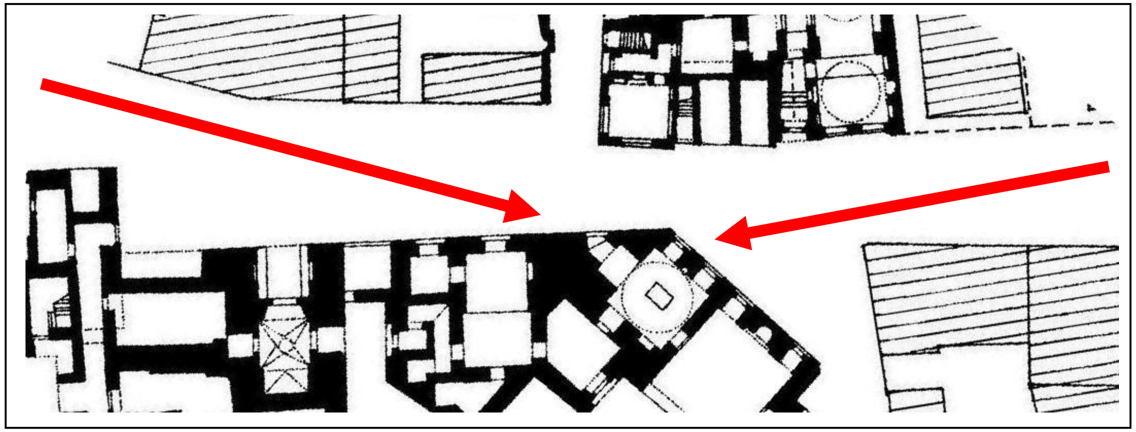


Figure 5-37: The position of the dome in Madrasa of Um Sultan Sha'ban

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Fig. (5-38).

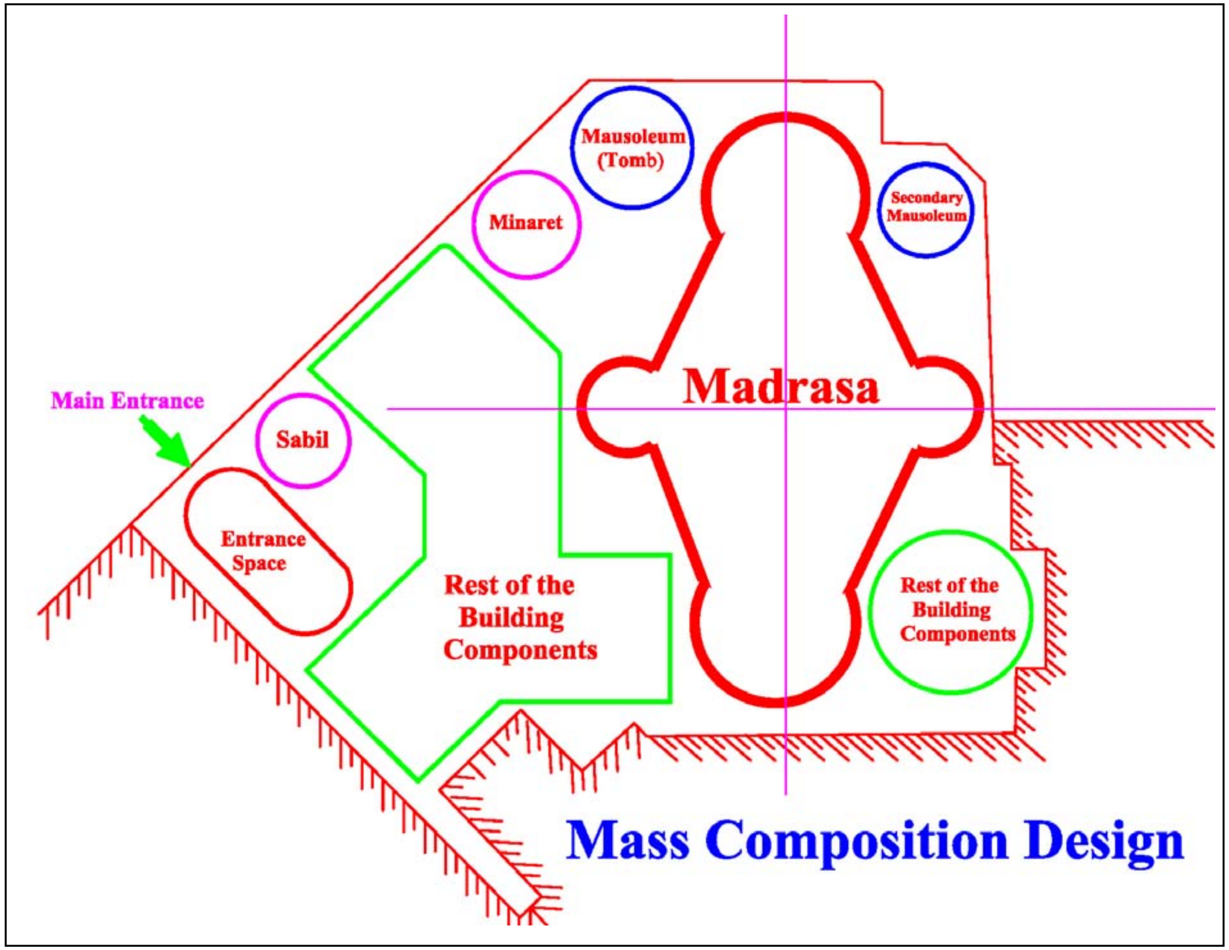
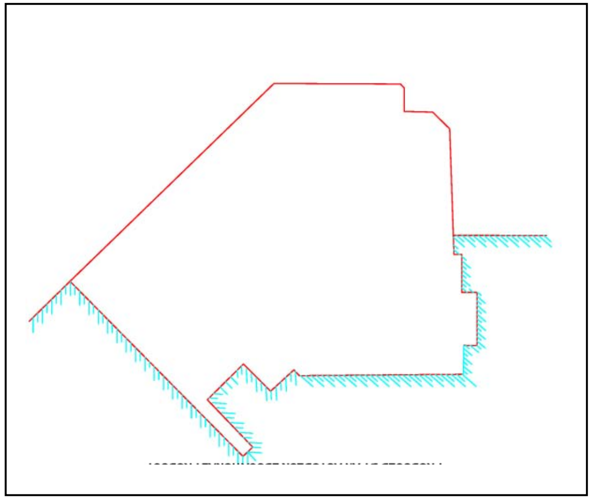
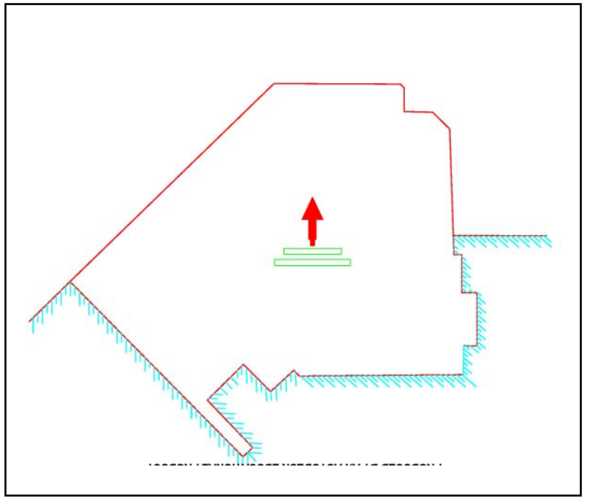


Figure 5-38: The mass composition in Madrasa of Um Sultan Sha'ban

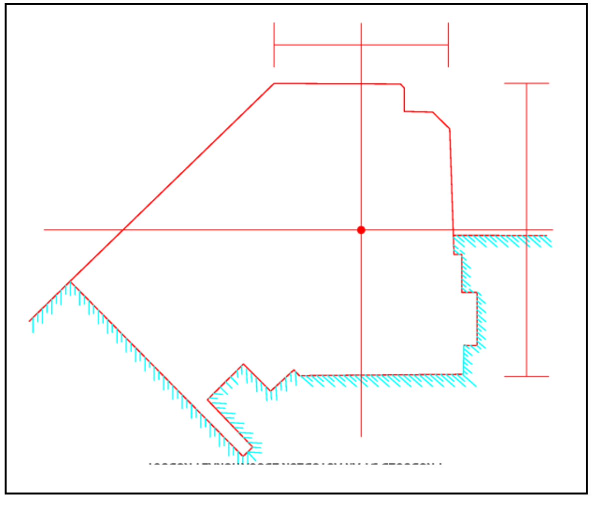
1- First Step: **Determining the Site Boundary, the Qibla Direction and the Sahn's Centre Point.**



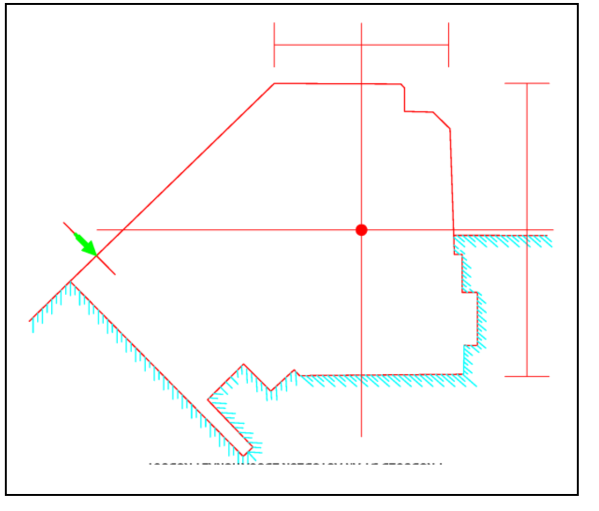
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

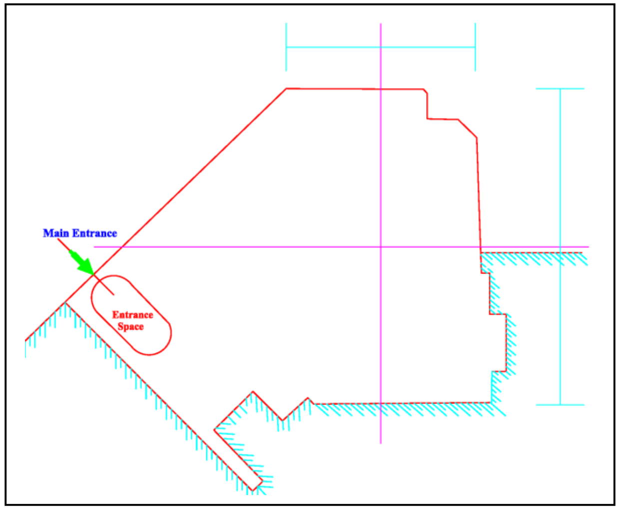


c- Determining the sahn's centre point

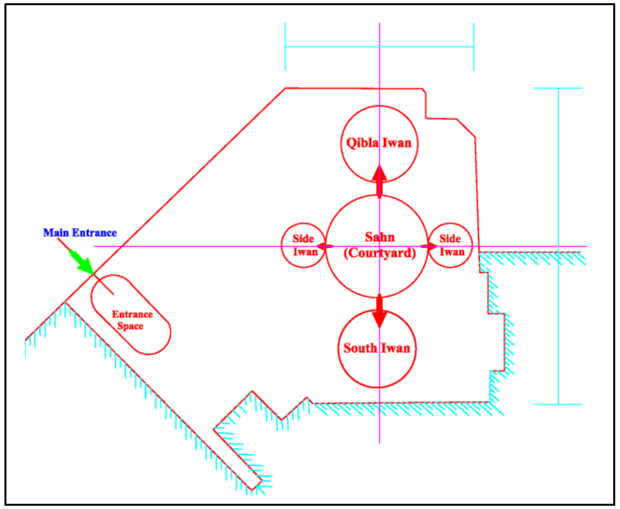


d- Adding the main entrance axis

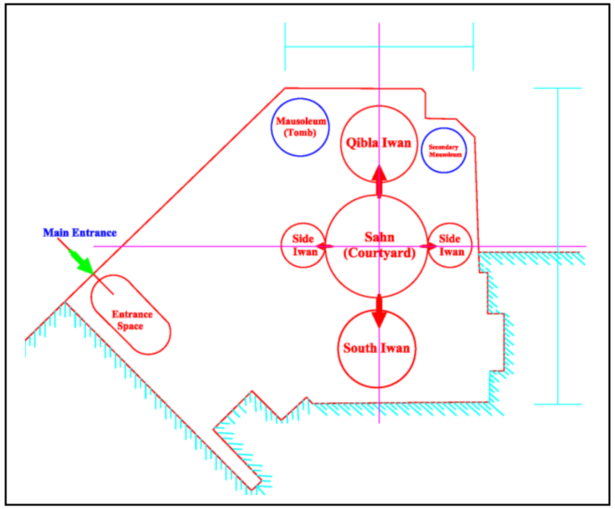
2- Second Step :- Determining the Functions' Relationships and the Users' Circulations Diagram.



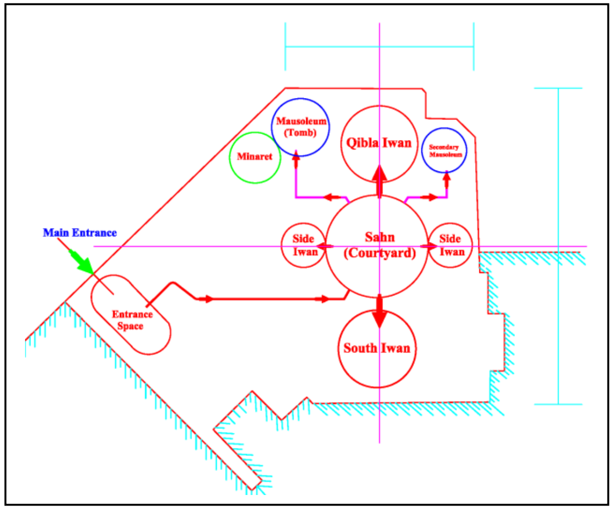
a- Determining the entrance spaces according to the entrances position



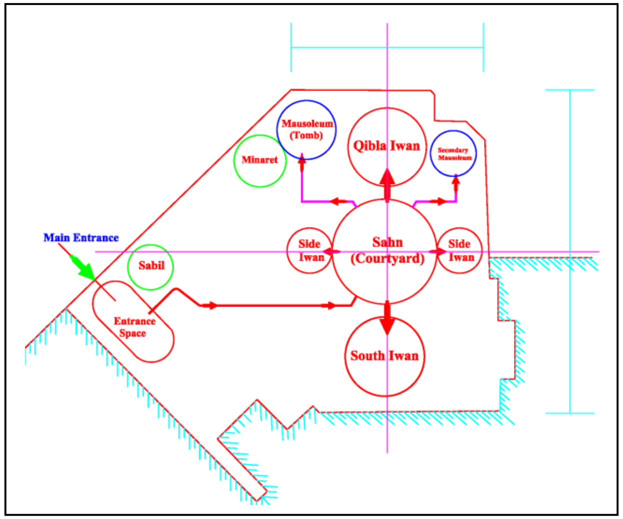
b- Determining the sahn and all iwans position



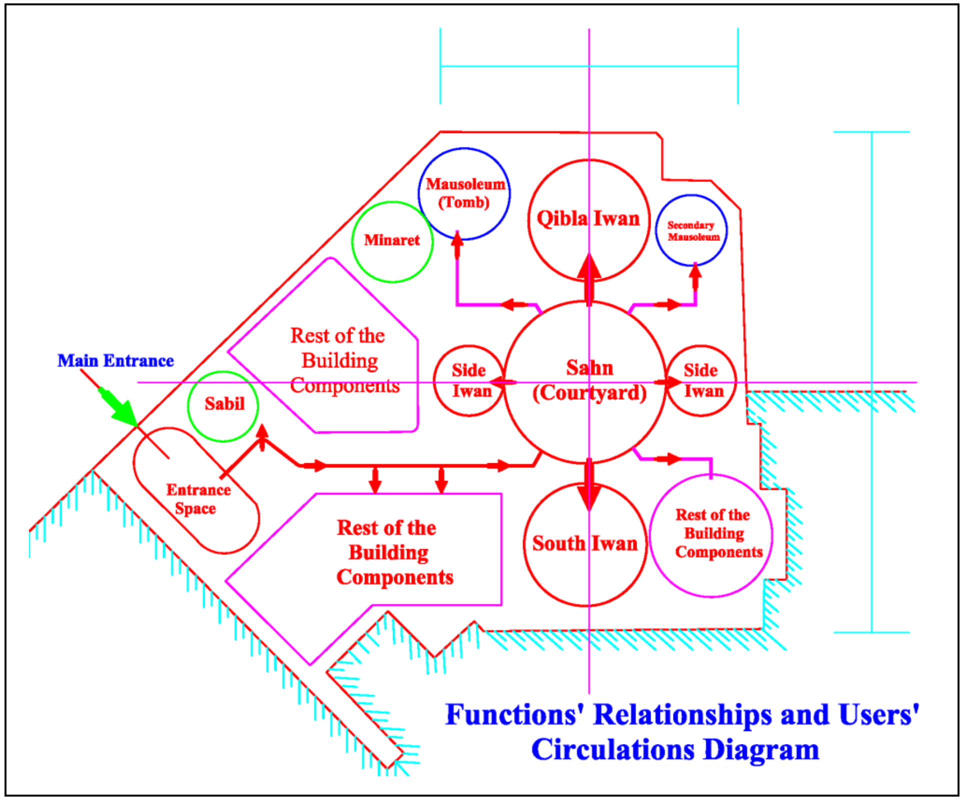
c- Determining the mausoleum position



d- Determining the minaret position

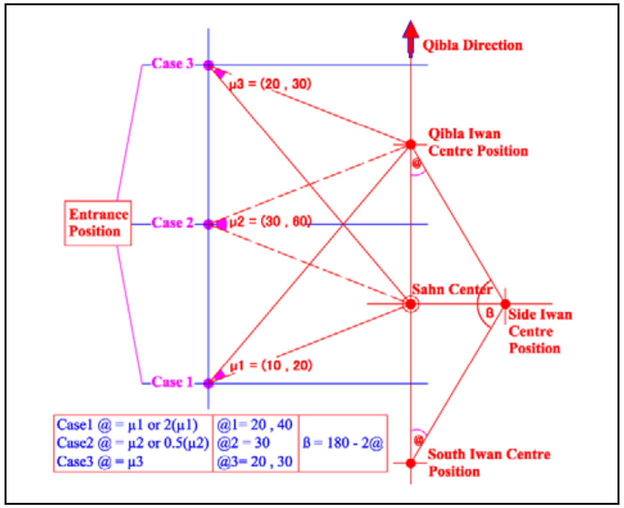


e- Determining the sabil position

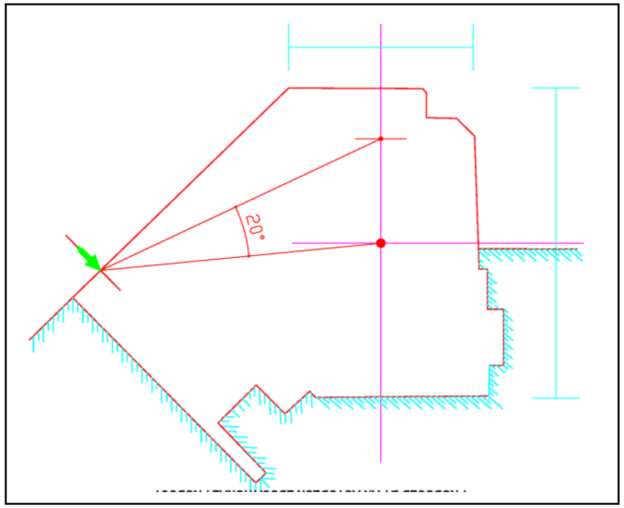


f- Determining the building's rest spaces and the final functions' relations diagram

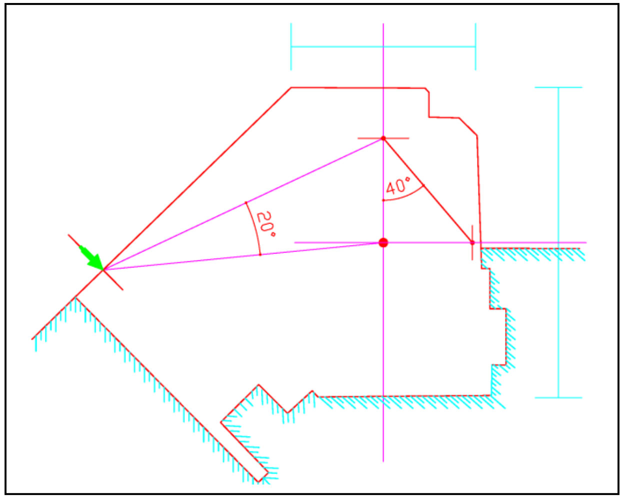
3- Third Step: Applying the Hidden Geometric System (Determining µ, @ and ß angles).



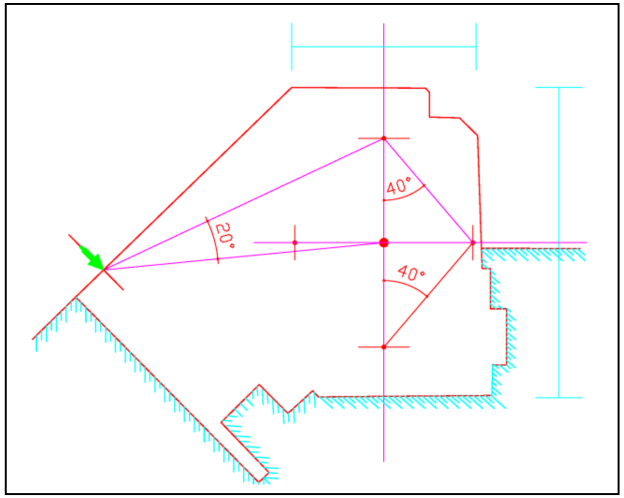
a- The hidden geometric system



b- Determining the qibla iwan's centre point



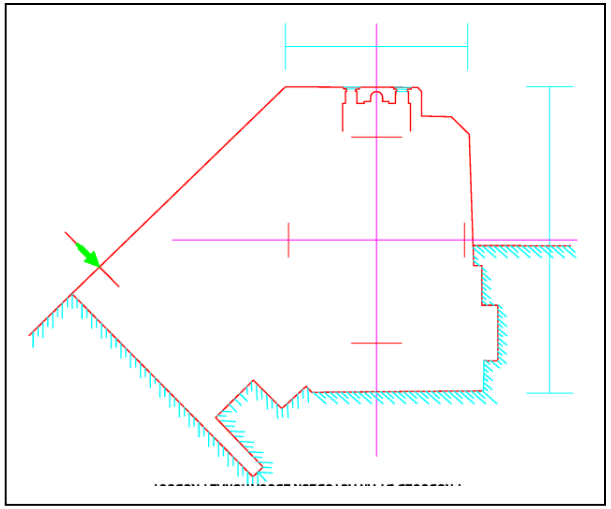
c- Determining the side iwan's centre points



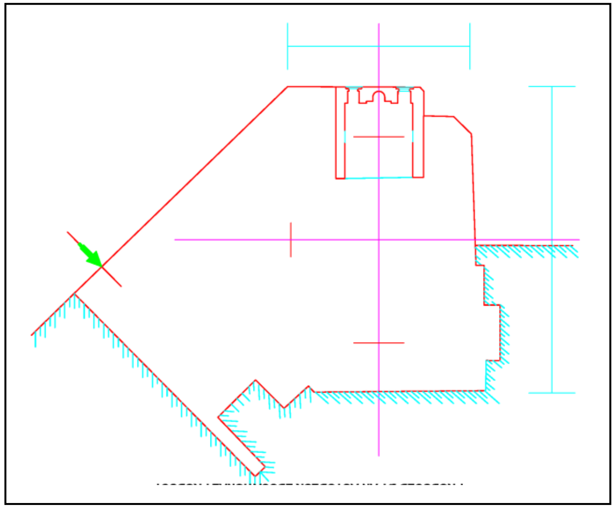
d- Determining the south iwan centre's point

<u>4- Fourth Step :</u>- Generating the building plan's design (The Design of the building in 2D).

1- Generating the Qibla Iwan (Praying Hall)

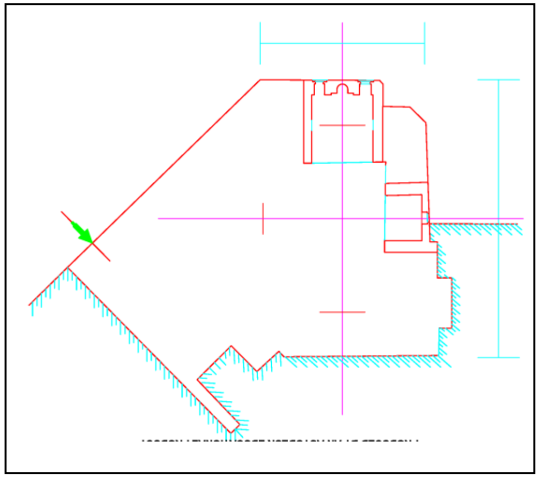


a- Designing the qibla wall

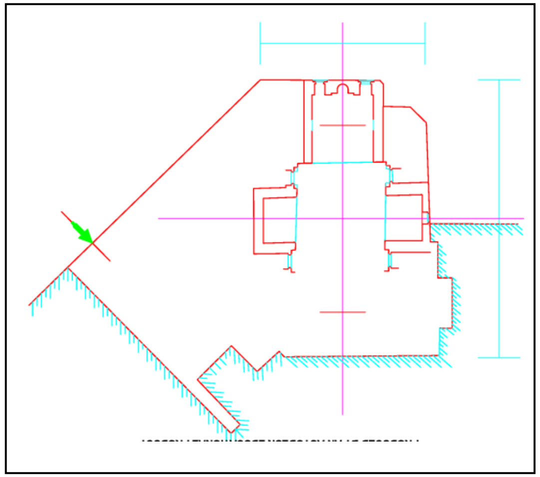


b- Completing the design of qibla iwan

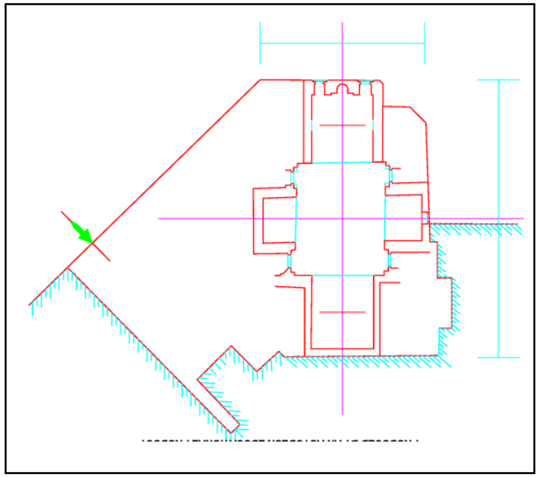
2- Generating the Sahn (Courtyard) and the Two Side Iwans



a- Designing one of the side iwans

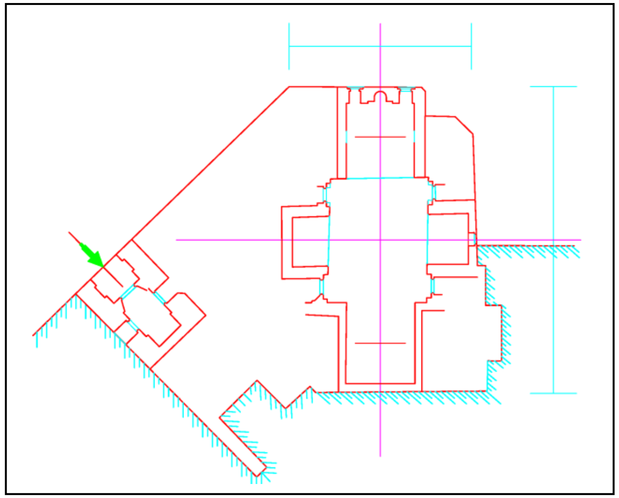


b- Designing the second side iwan

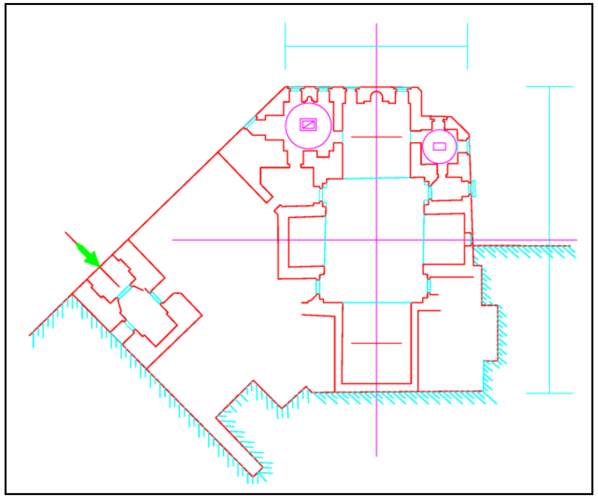


c- Completing the sahn and the south iwans design

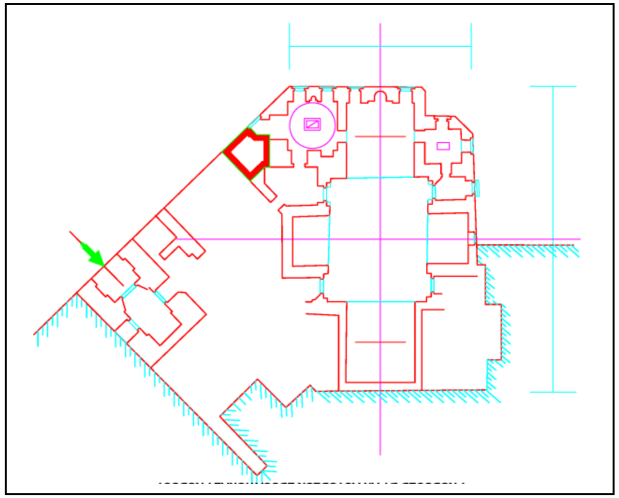
3- Adding the Entrance Design



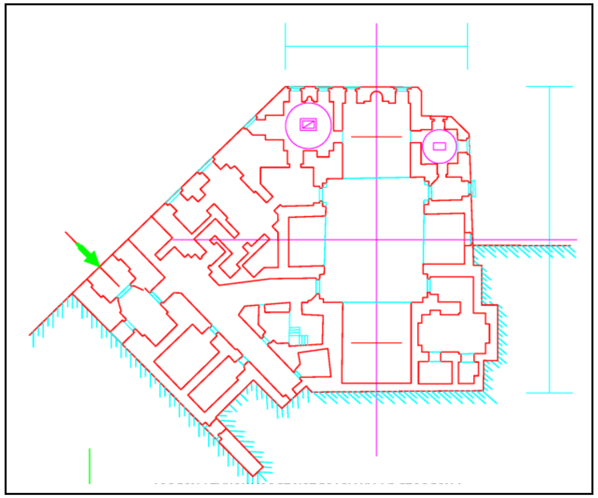
4- Determining the Position of the Mausoleum



5- Determining the Position of the Minaret



6- Completing the Building Spaces



7- The Final Building Plan with the H.G.D. System

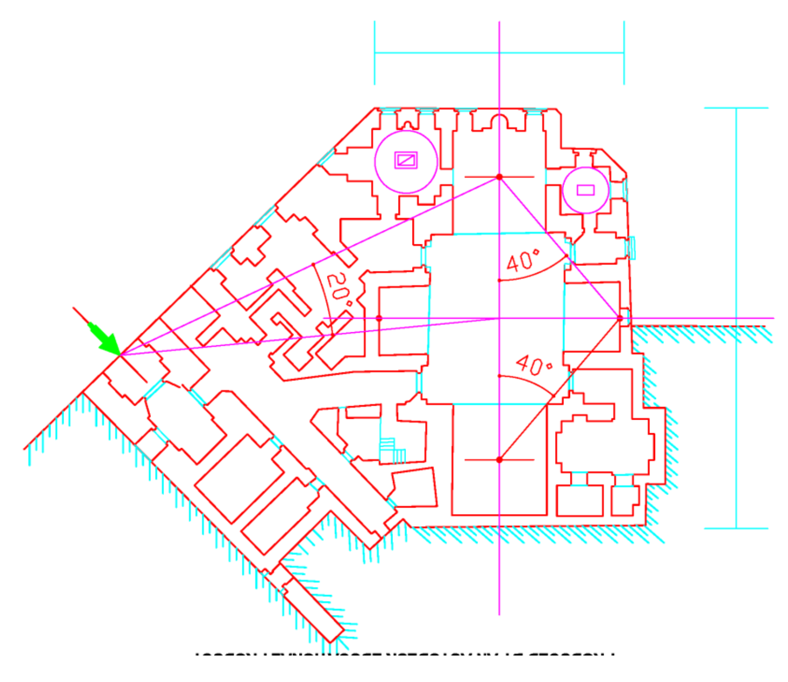


Figure 5-39: The final plan with the hidden geometric design system in Madrasa of Um al-Sultan Sha'ban

8- Generating the Final Building Plan

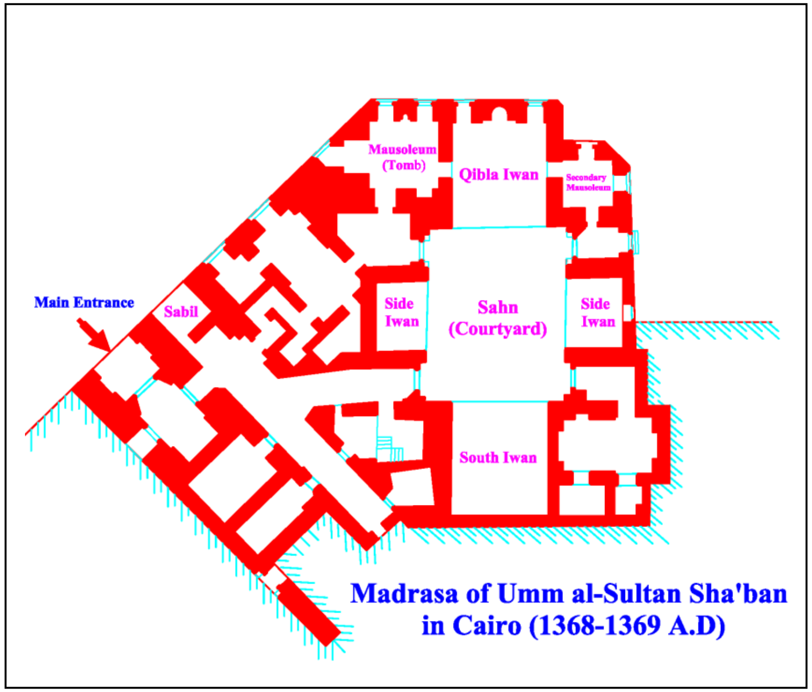


Figure 5-40: The final plan of Madrasa of Um al-Sultan Sha'ban

<u>5- Fifth Step:</u> Applying the Interior Space Design Rules.

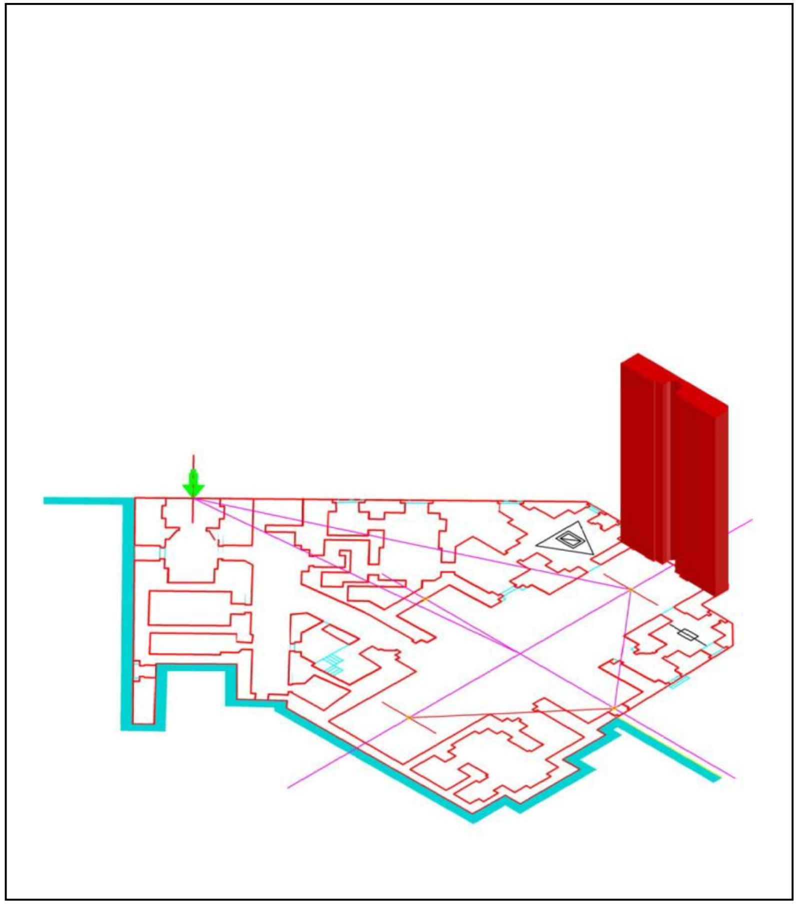
These are the results of applying the interior space design rules in Madrasa of Um al-Sultan Sha'ban:

* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.
* The entrance spaces are roofed and their height is equal to the building's total height.
* The design follows the roofed courtyard type.

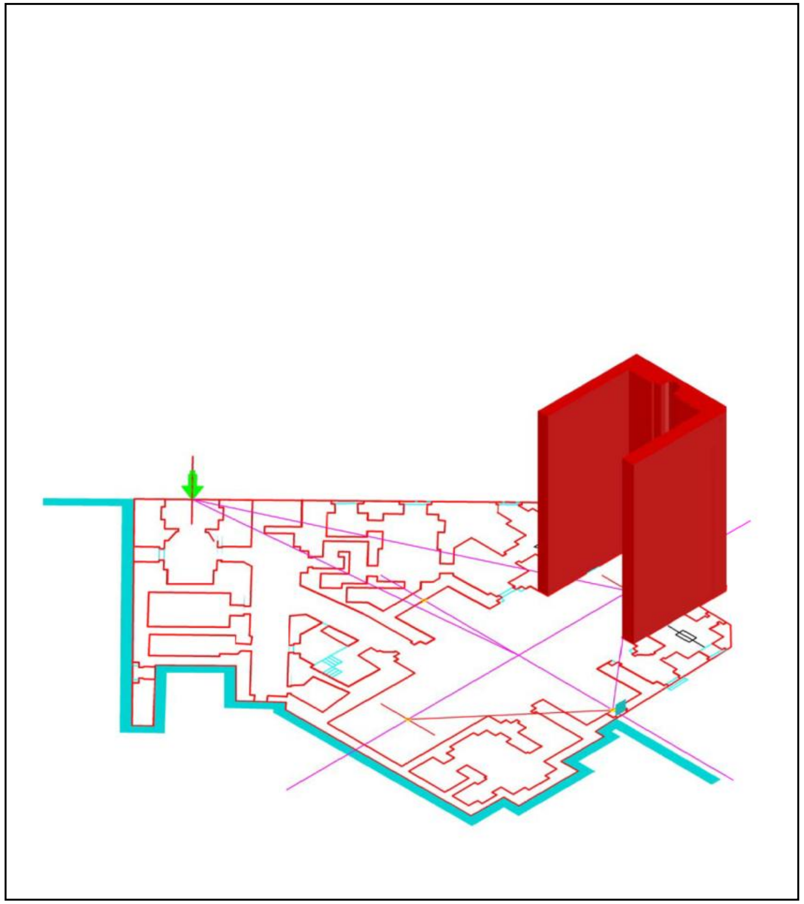
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans which he has designed into three-dimensional spaces.

<u>6- Sixth Step:</u> Generating the Building Spaces' disposition (The Design of the building in 3D).

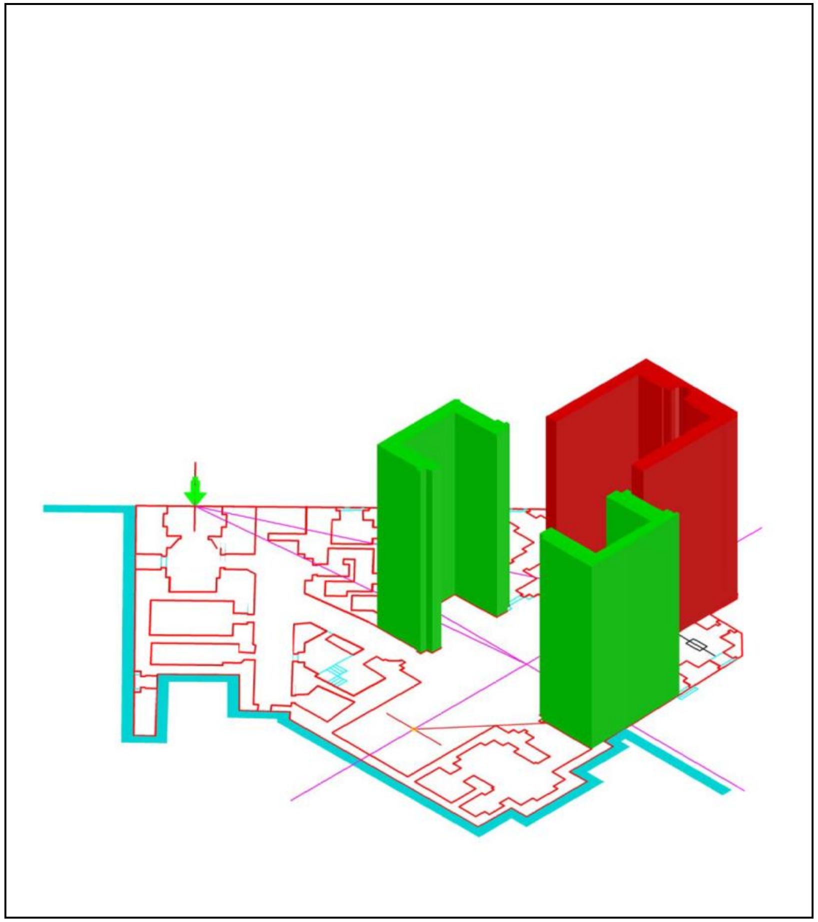
1- Constructing the Qibla Wall



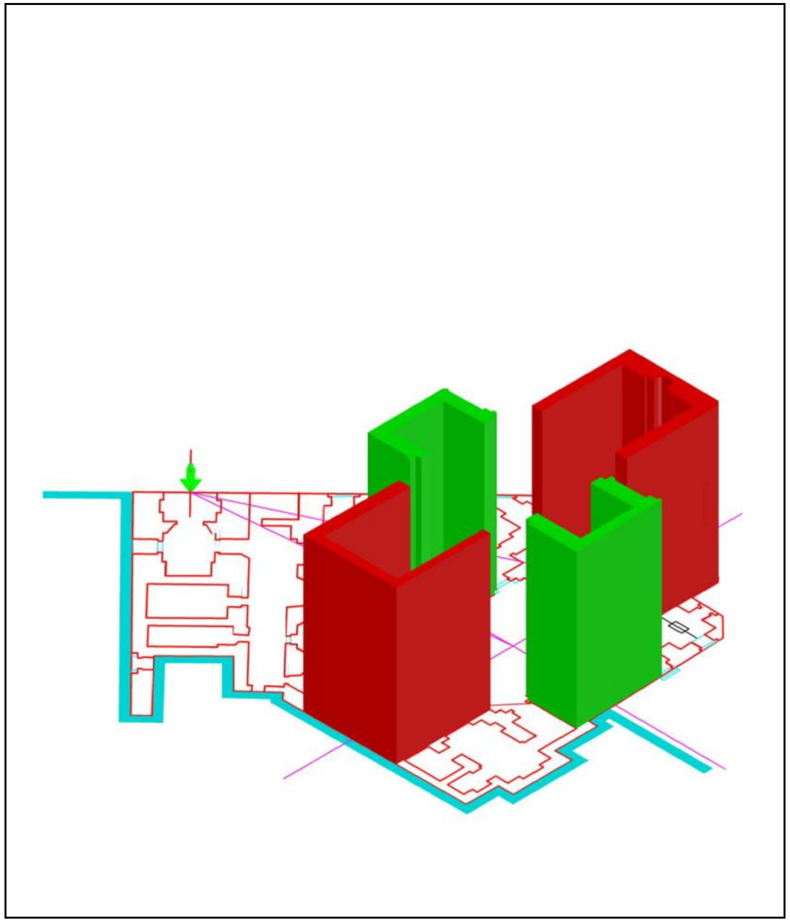
2- Completing the Qibla Iwan



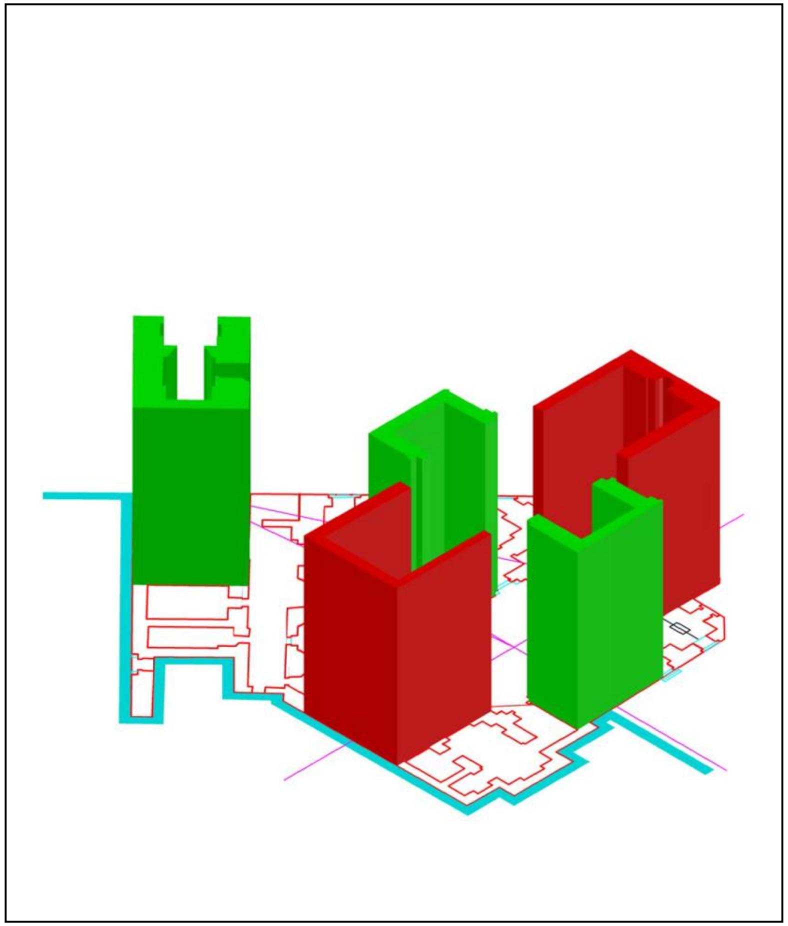
3- Constructing the Side Iwans



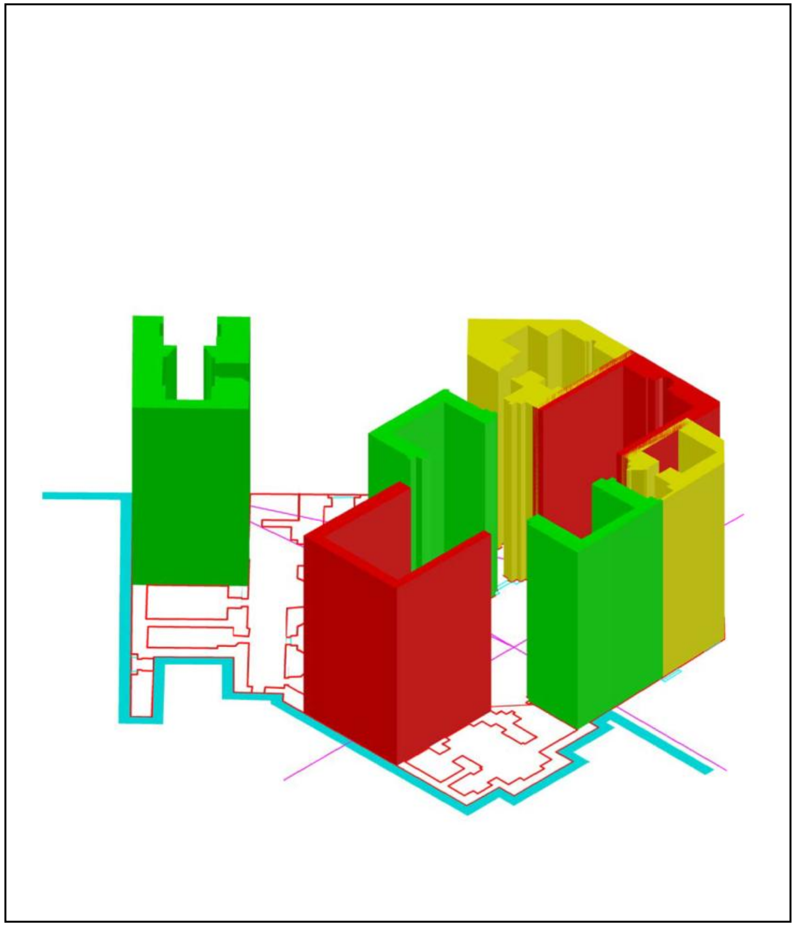
4- Constructing the South Iwan



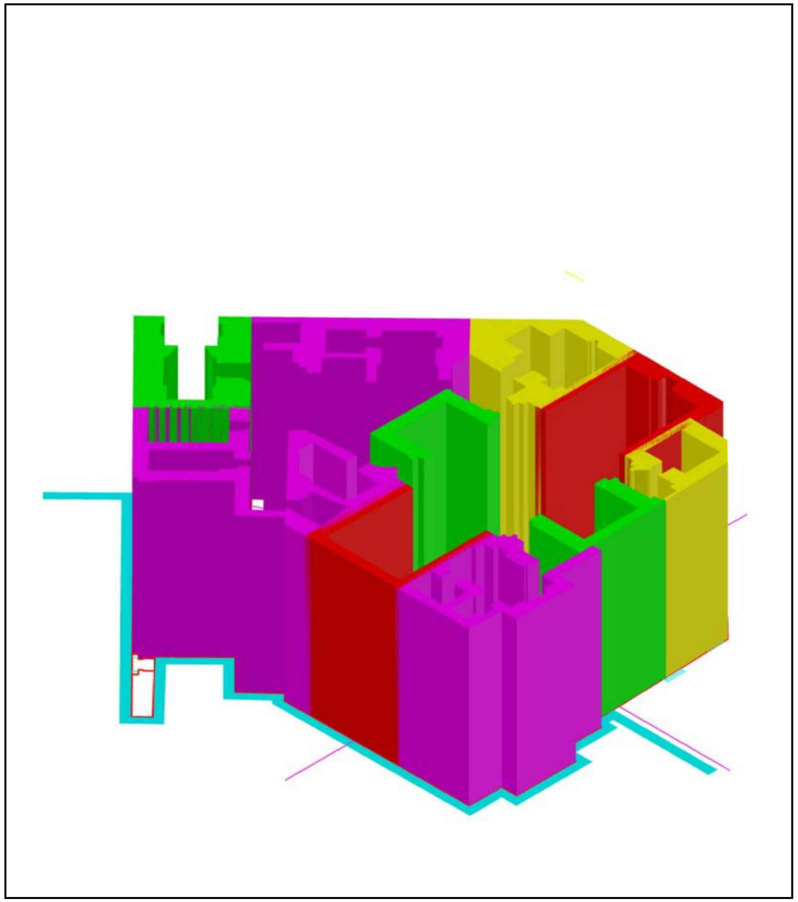
5- Constructing the Entrance and its Spaces



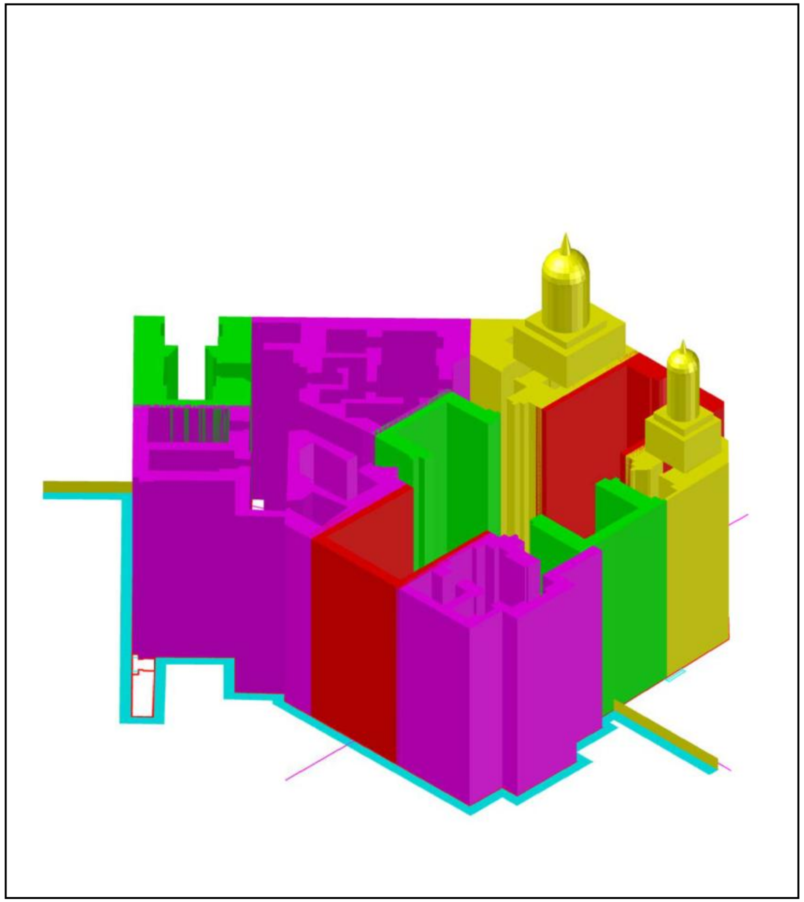
6- Constructing the Mausoleum Space



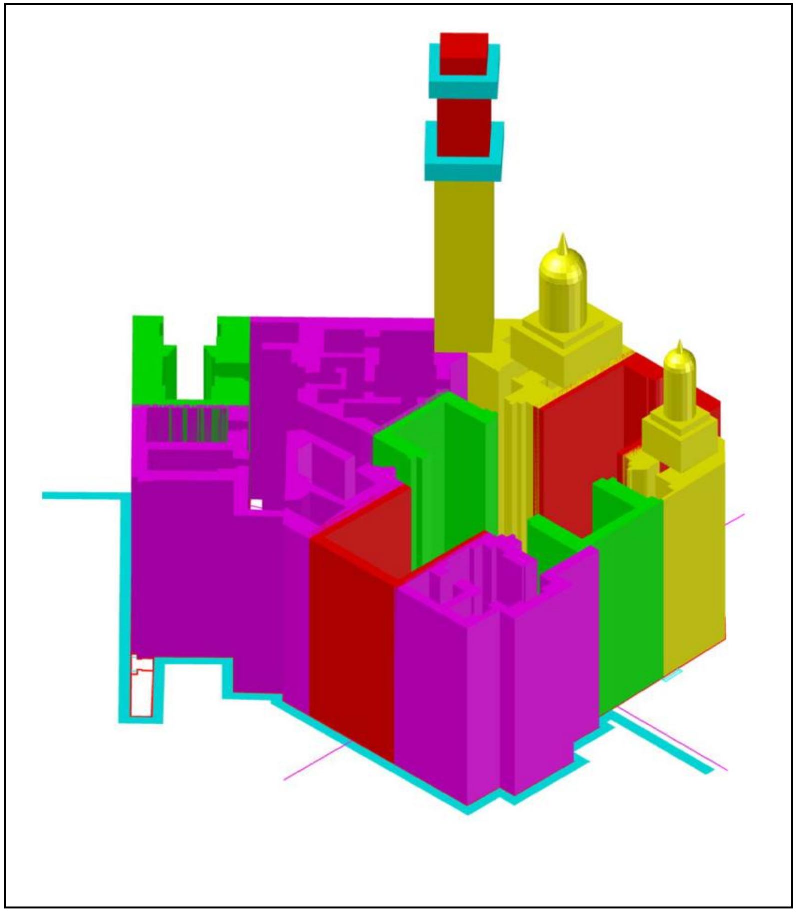
7- Constructing the Rest of the Building's Spaces



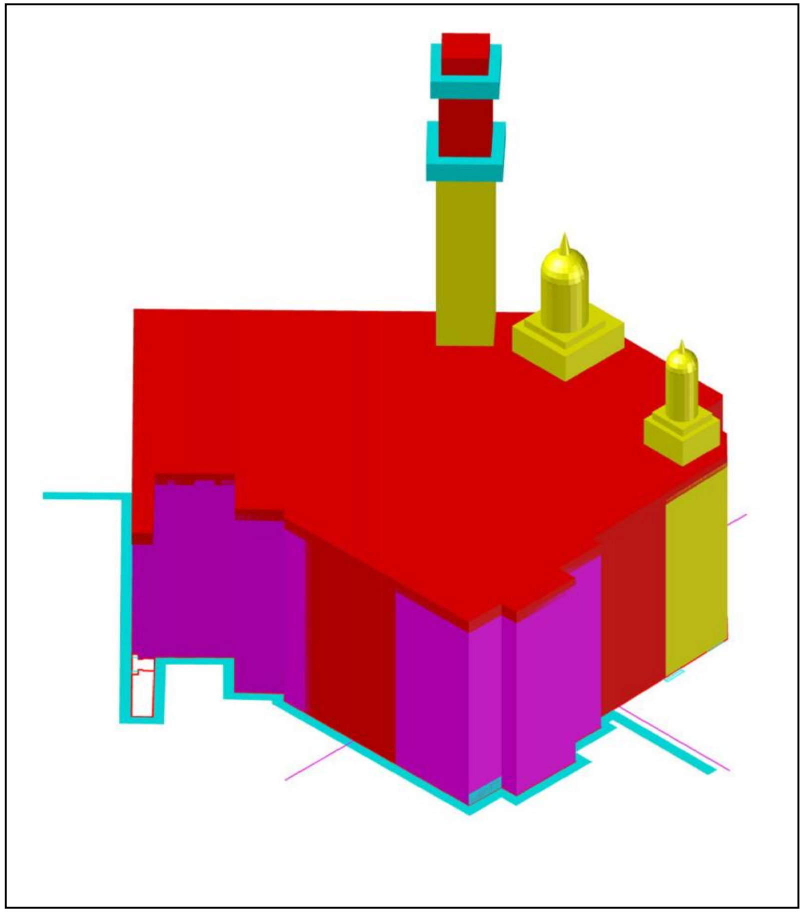
8- Constructing the Mausoleums' Domes



9- Constructing the Minaret



10- Roofing the Building



5.2.1.4 Madrasa of Sultan El-Ashraf Barsbay (1423-4 A.D.)

Sultan king El-Ashraf Barsbay al-Duqmaqi al-Zahir who ordered the building of this madrasa was a mamluk of al-Zahir Barquq who released him and kept him in his service. The madrasa is located in el-Mu'izz street in a section known as Ashrafiya near al-Sagha (Goldsmith), the site was previously occupied by old shops and tenant houses, yards and markets that were demolished for building the madrasa [(OICC),1992]p.190.

1- General Description:

Variant Names	* Madrasa of Sultan El-Ashraf Barsbay. * Sultan al-Ashraf Barsbay, Mosque/Madrasa/Khanqah. * Sabil-Kuttab and Mausoleum complex of Sultan al-Ashraf Barsbay. * Al-Ashrafiya. * Funerary Complex of Sultan al Ashraf Barsbay at Suq al Nahhasin.
Street Address	Al-Mu'izz Li-Din Allah Street
Location	Cairo, Egypt
Client	Sultan al-Ashraf Barsbay
Date	15^{th} (1425 A.D.)
Style/Period	Mamluk (Circassian)
Building Types	Complex (Educational, Funerary, Religious)
Building Usage	Madrasa, Mausoleum, Sabil, Mosque.

Table 5-4: The general description of Madrasa of Sultan El-Ashraf Barsbay

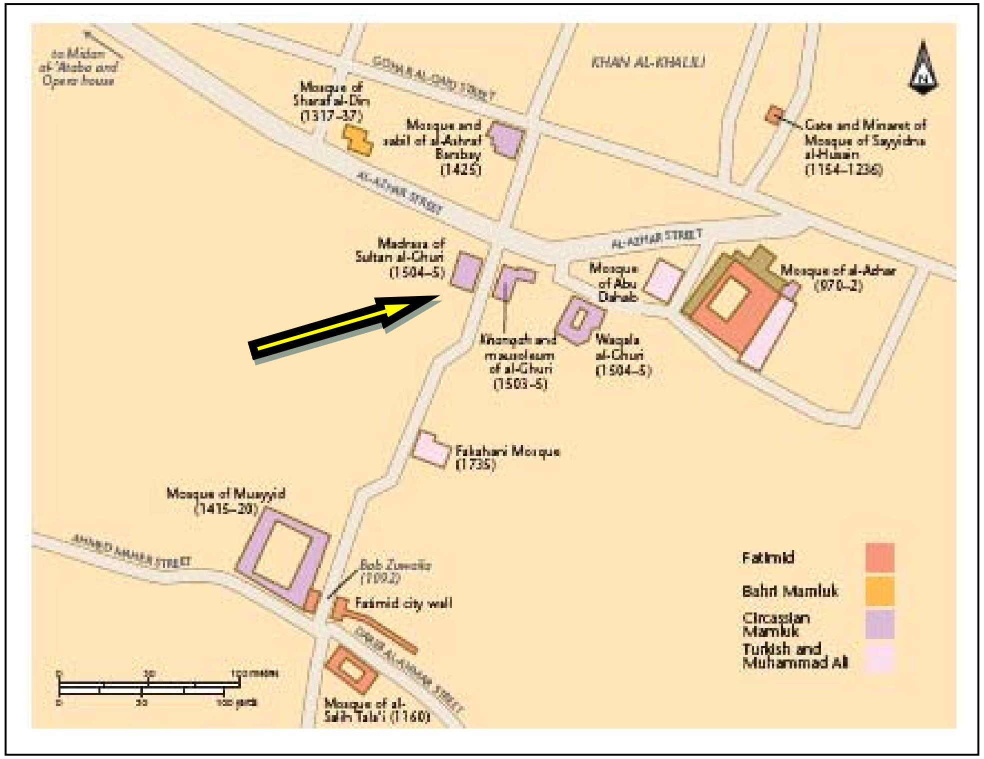


Figure 5-41: The site of Madrasa of Sultan El-Ashraf Barsbay

2- Architectural Description

This madrasa is situated at Shari' al-Mu'izz li-Din Illah at its junction with Shari' Gawhar al-Qa'id. It was founded by al-Malik el-Ashraf Barsbay who began its construction in 826 A.H. (1424 A.D.) [(OICC),1992]p.190.

a- The Layout

The building mass composition consists of three main masses. The first is the mass of the madrasa, the second is of the mausoleum and the third is the mass of the entrance and the sabil. The plan of the madrasa and mausoleum is shifted to accommodate the qibla orientation.

b- The Plan

It is a four-iwan design dedicated to Sufis, who wished to study the four rites of Islamic Law according to a traditional madrasa structure. This madrasa figures are important for understanding the change in function and form of Burji religious institutions.
This mosque was built according to the four-iwan madrasa plan, i.e. an open sahn with four iwans around it, the mausoleum being placed next to the qibla iwan which, as it is in other madrasas, is the most important and is more heavily decorated than the others. The important features in the qibla iwan which attract attention, are its beautiful marble floor and its fine stucco windows.

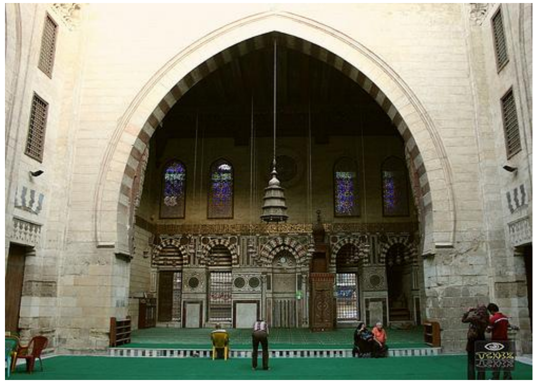


Figure 5-42: The elevation of the qibla iwan from the courtyard in Madrasa of Sultan Barsbay

c- The Facades

The facade between the entrance and the mausoleum has two recessed panels crowned with stalactites; in each recess there are two sets of windows. It is crowned with trefoil cresting. At the northern end of the facade there is a stone dome, decorated with a chevron pattern carved on the stone, see Fig. (5-43).
The entrance is in the southern end of the main facade which overlooks Shari' al-Mu'izz Li-Din Illah, with a sabil and a kuttab next to it. The entrance is ornamented with colored marble and is vaulted with stalactites. The wooden door is plated with brass tracery, with a medallion in the centre. The four corners and two upper and lower bands of inscription bear the name of the founder and date of renovation. Above the medallion there are two knockers of pierced brass.

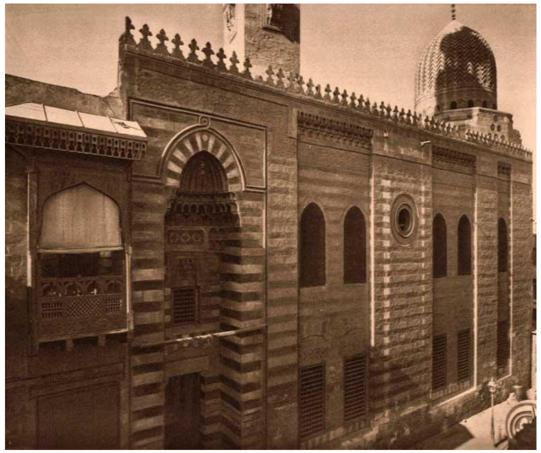


Figure 5-43: The main facade in Madrasa of Sultan Barsbay

d- The Minaret

The minaret, with its first square storey, the second one cylindrical and ornamented with an interlacing pattern, and the third one a pavilion of marble columns with a finial on top, stands on the right-hand side of the entrance, as shown in Fig. (5-44).

e- The Mausoleum

The mausoleum's central domed plan is connected to the madrasa through the sahn by a small entrance passage. There is no mihrab in the madrasa's mausoleum, because accommodating one would have left no room for a window facing al-Mu'izz Street, which would have deprived the tomb of its crucial visual contact with the street. The mihrab, a highly decorative feature which emphasized the religious character of the mausoleum, is replaced here by the blessings of the passers-by.

3- Applying the Geometric Generative Technique: (Technique Steps)

The geometric generative technique steps are applied in the site of Madrasa of Sultan El-Ashraf Barsbay in order to show how the early designer generated or suggested the building architecture space design.

Figure 5-44 The minaret composition in Madrasa of Sultan Barsbay

<u>Pre-Design step:</u>

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building's entrance so that it is in relation to the minaret to make some kind of visual emphasis to the building.

b- Study the position of the dome.

The designer chooses the position of the building's dome so that it is plays the landmark's role for the building. He put it in the building corner, at Shari' al-Mu'izz li-Din Illah at its junction with Shari' Gawhar al-Qa'id, as shown in Fig. (5-45).

c- Study the position of the minaret.

The designer chooses the position of the building's minaret so that it is plays the role of the landmark to the site, and the pedestrians can see it from a distance, as shown in Fig. (5-46).

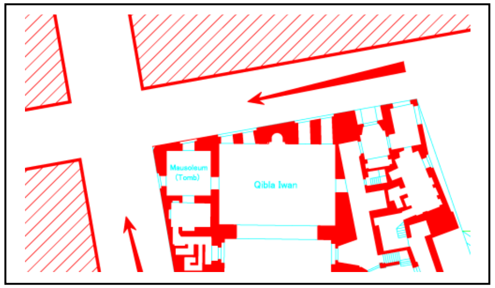


Figure 5-45 El The position of the dome in Madrasa of Sultan Barsbay

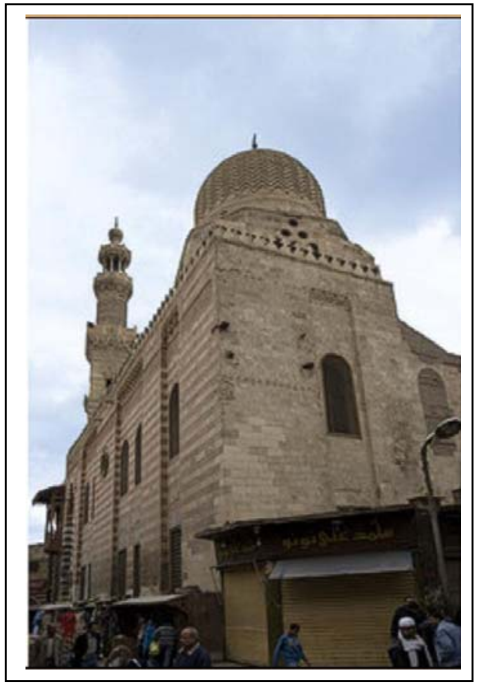


Figure 5-46 The view of the minaret and the dome from the side of the street in Madrasa of Sultan Barsbay

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Fig. (5-47).

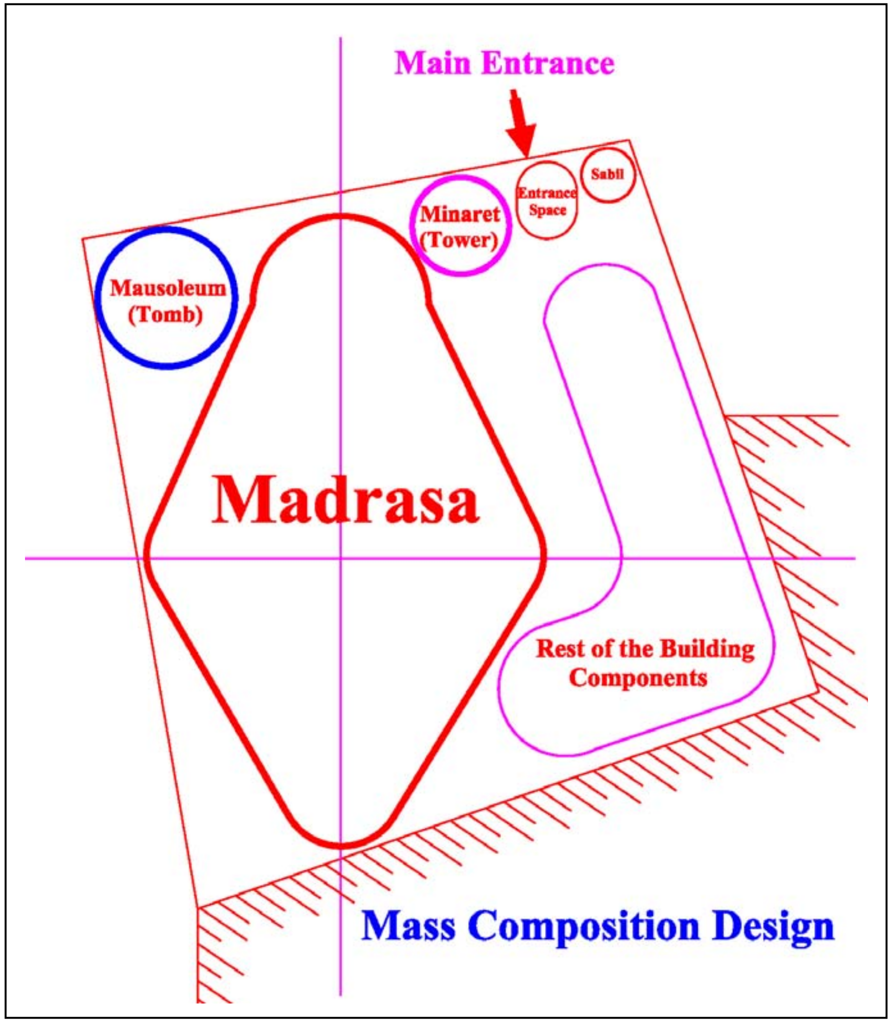
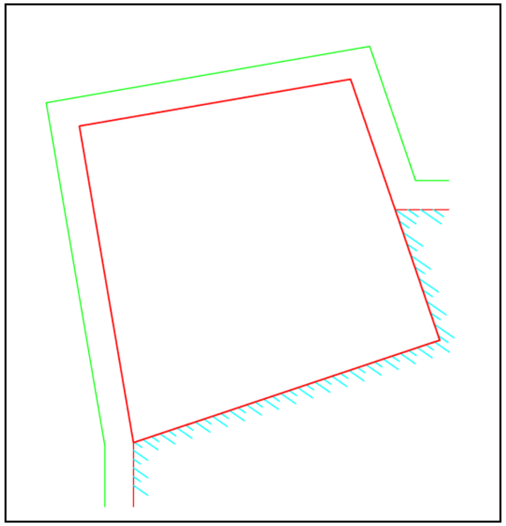
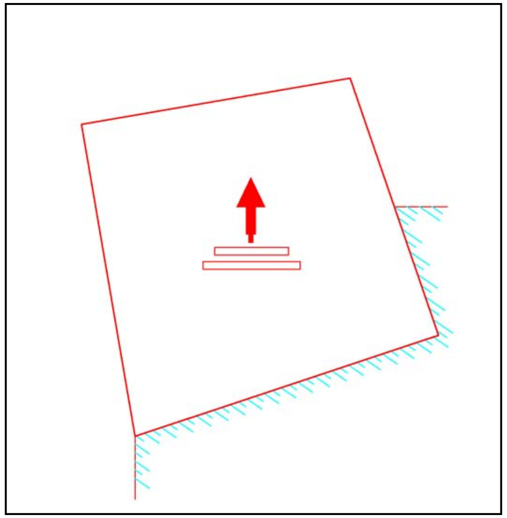


Figure 5-47 The mass composition of Madrasa of Sultan Barsbay

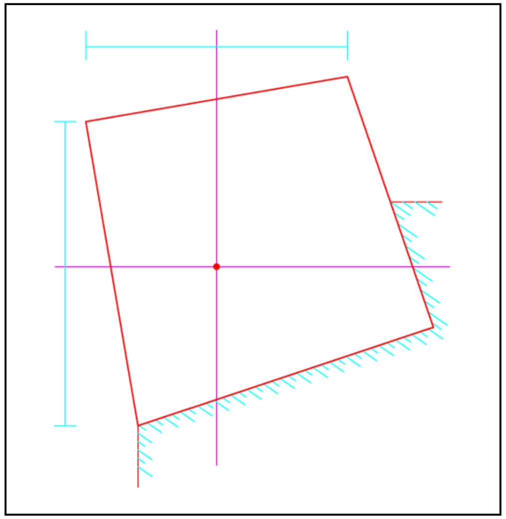
<u>1- First Step:</u> Determining the Site Boundary, the Qibla Direction and the Sahn's Centre Point.



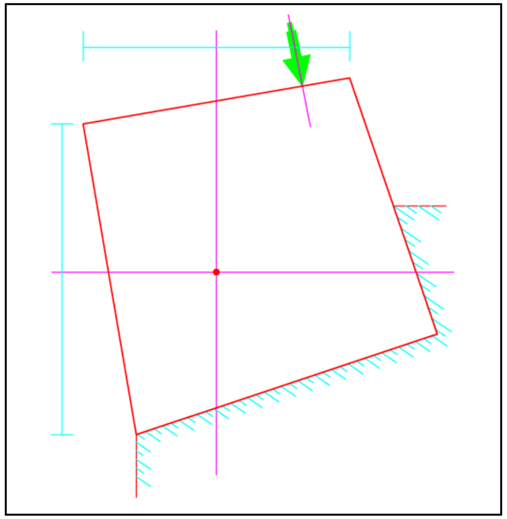
a- Determining the building site boundary



b- Determining the qiblaa direction (Makkah direction)

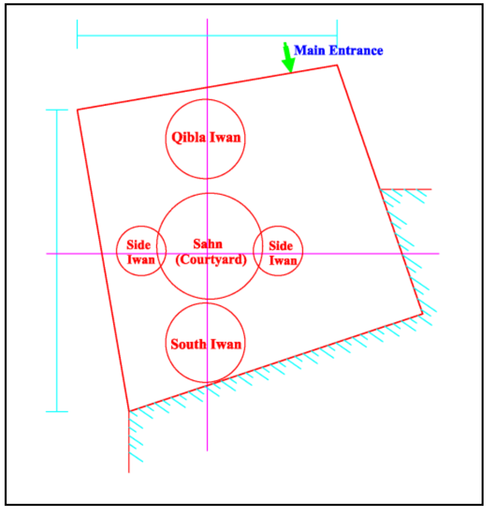


c- Determining the sahn's centre point

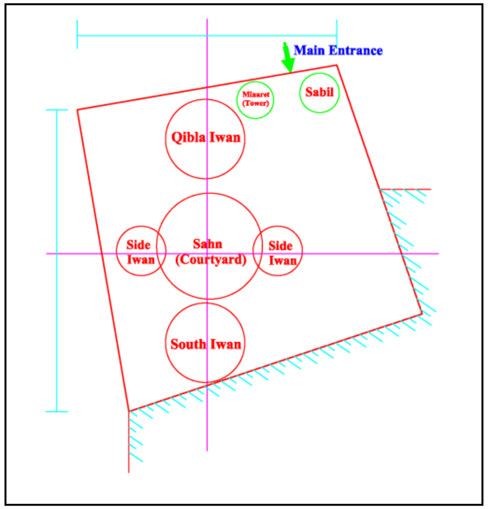


d- Adding the entrances axis

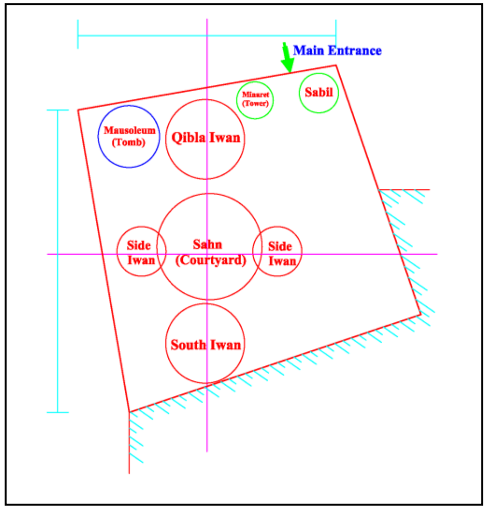
2- Second Step: Determining the Functions' Relationships and the Users' Circulations Diagram.



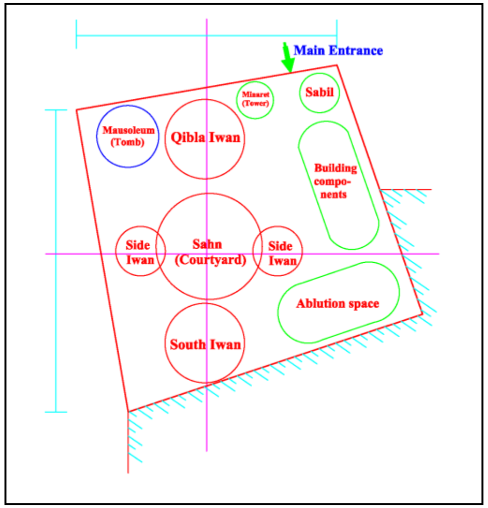
a- Determining the position of the Sahn and all Iwans



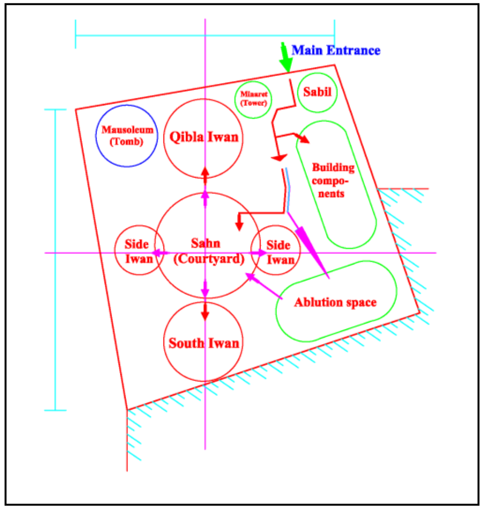
b- Determining the position of the minaret



b- Determining the position of the mausoleum



c- Determining the position of the ablution space



d- Determining the relationships between different functions

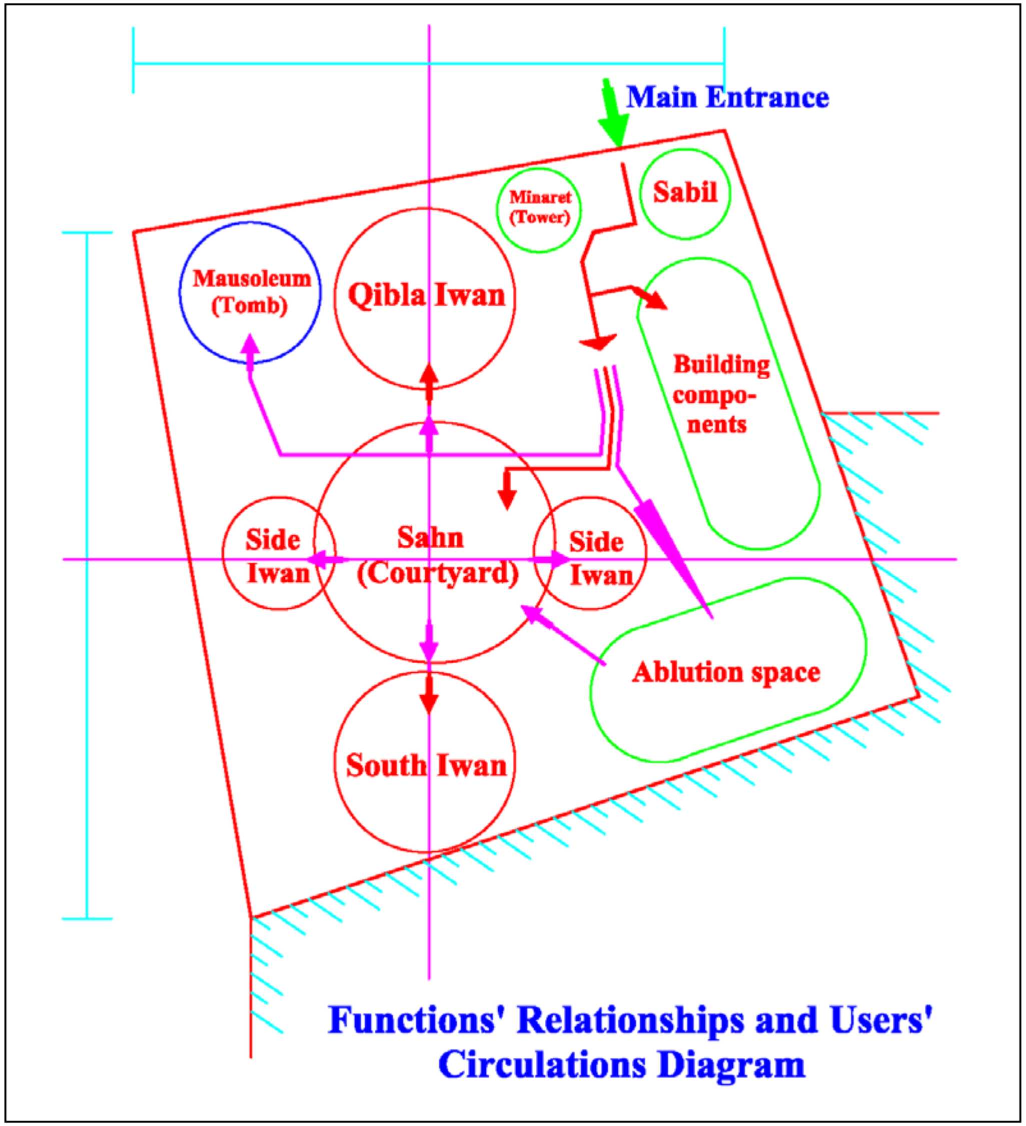
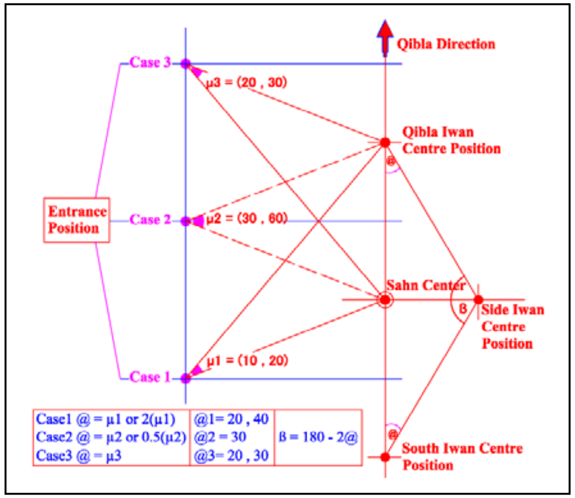
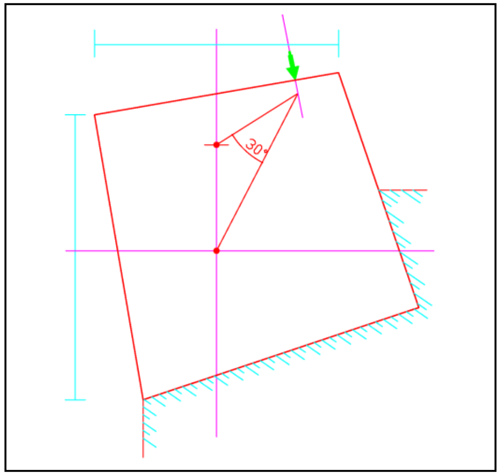


Figure 5-48: The final functions' relationships diagram in Madrasa of Sultan Barsbay

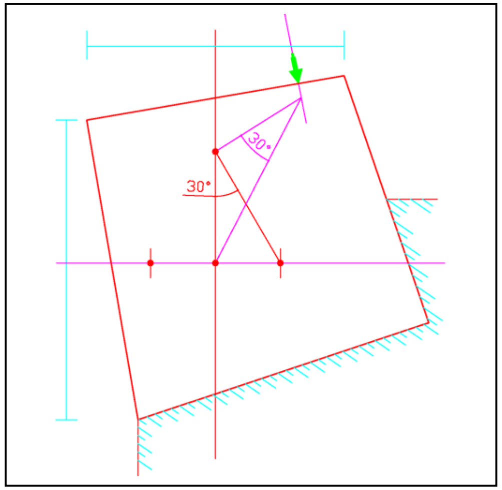
3- Third Step: Applying the Hidden Geometric System (Determining µ, @ and ß angles).



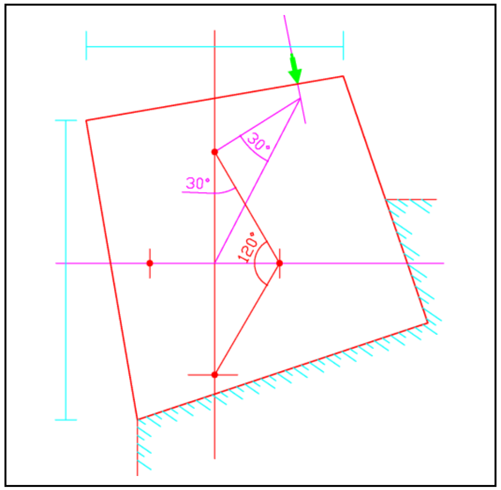
a- The hidden geometric system
(Determining the **µ, @** and **ß** angles)



b- Determining the qibla iwan's centre point
(Applying the µ angle)



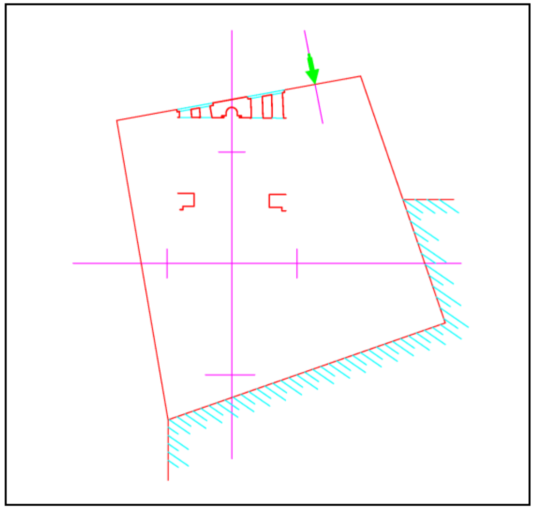
c- Determining the Side Iwan's centre points
(Applying the @ angle)



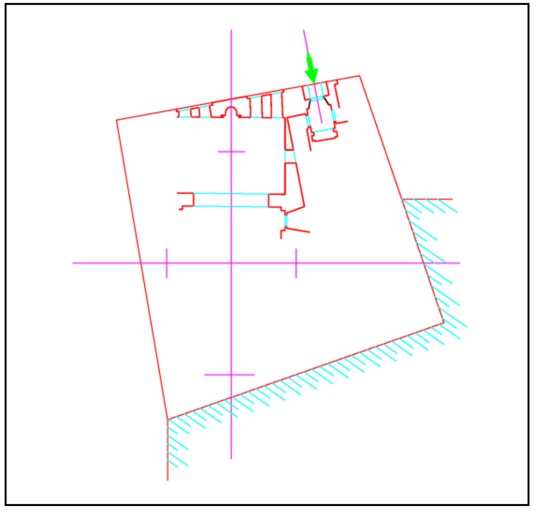
d- Determining the south iwan's centre point
(Applying the ß angle)

<u>4- Fourth Step :</u>- Generating the Building Plan's Design (the design of the building in 2D).

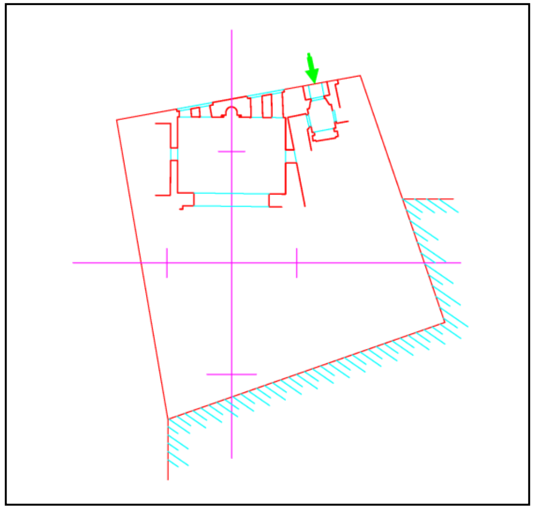
1- Generating the Qibla Iwan (Praying Hall)



a- Designing the qibla wall

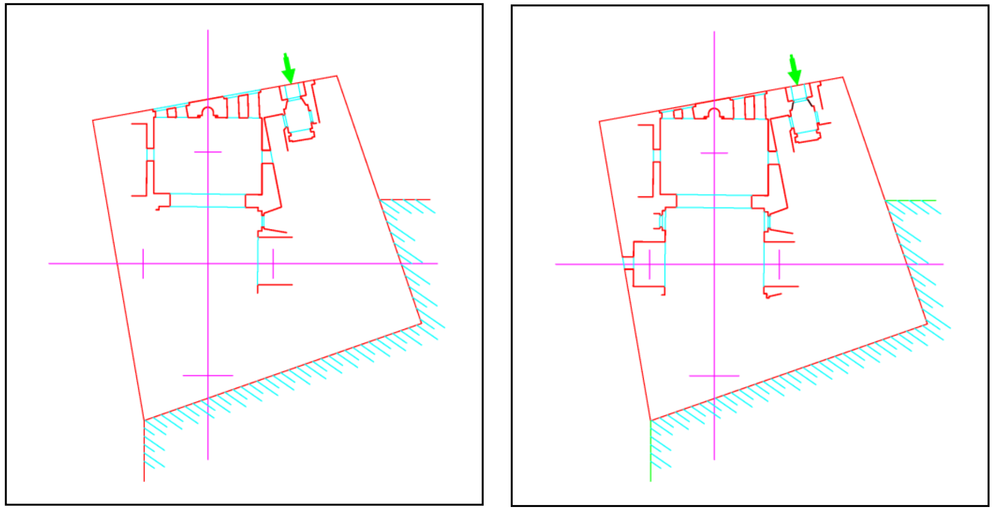


b- Designing the qibla iwan entrance wall

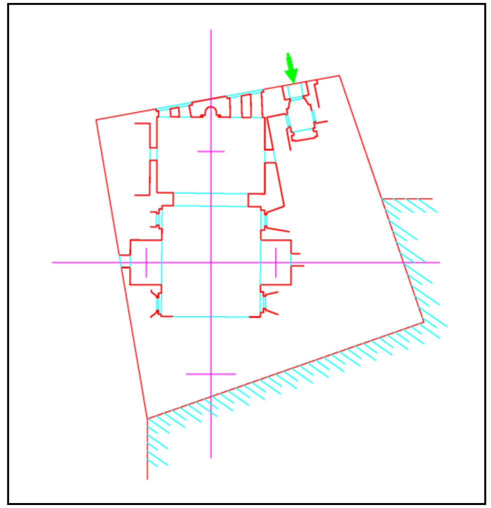


c- Completing the design of qibla iwan

2- Generating the Sahn (Courtyard) and the Two Side Iwans

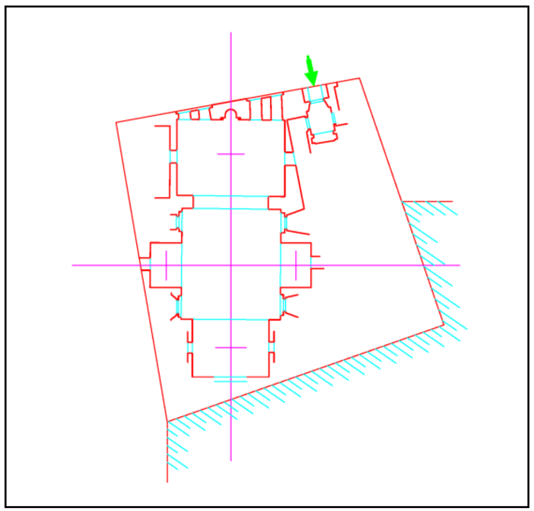


a- Beginning with the design of one of the side iwans

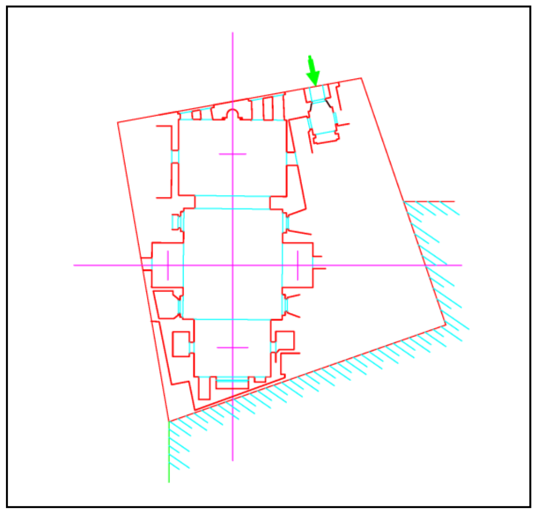


b- Completing the sahn and sides iwans design

3- Generating the South Iwan

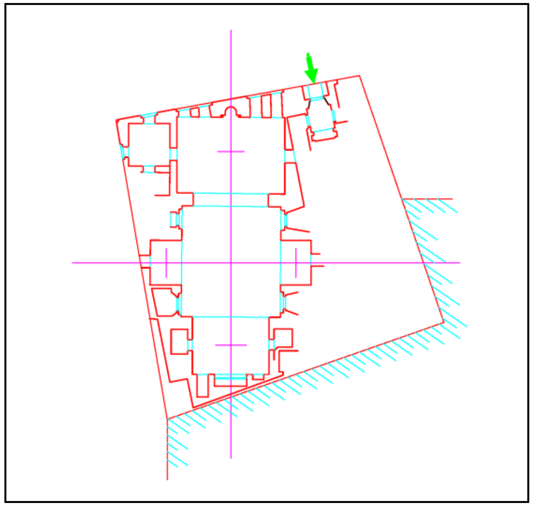


a- Designing the south iwan



b- Completing the cells around the south iwan

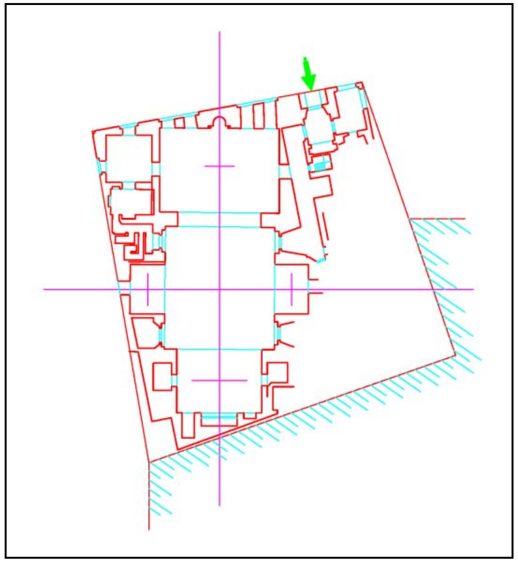
4- Generating the Mausoleum



a- Determining the main space of the mausoleum

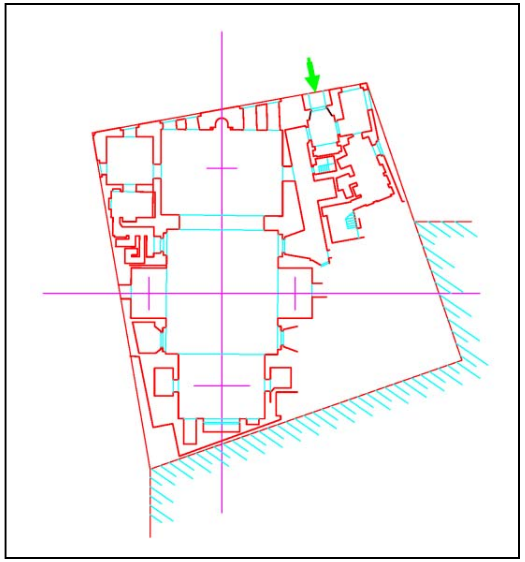
b- Completing the final design of the mausoleum

5- Placing the Sabil-Kuttab

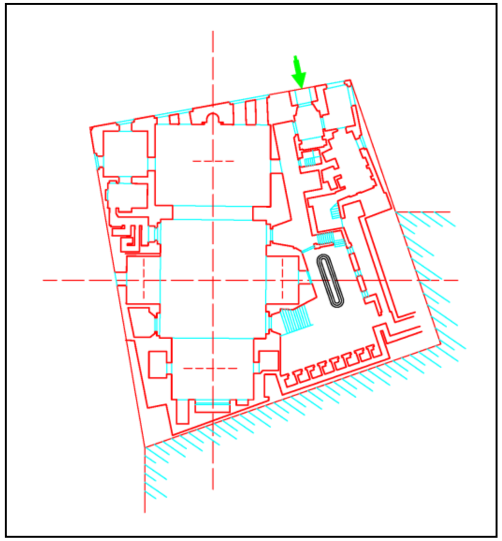


6- Designing the Entrance

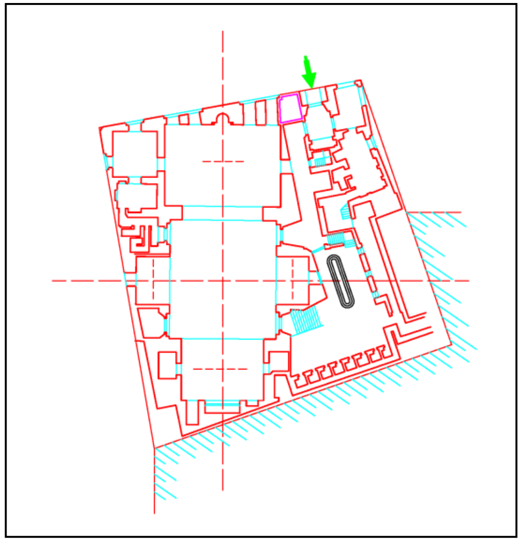
a- Adding the entrance components spaces
c- Designing the path from the entrance to the sahn
b- Adding the entrance cells



7- Placing the Ablution Space



8- Placing the Minaret



9- The Final Building Plan with the H.G.D. System

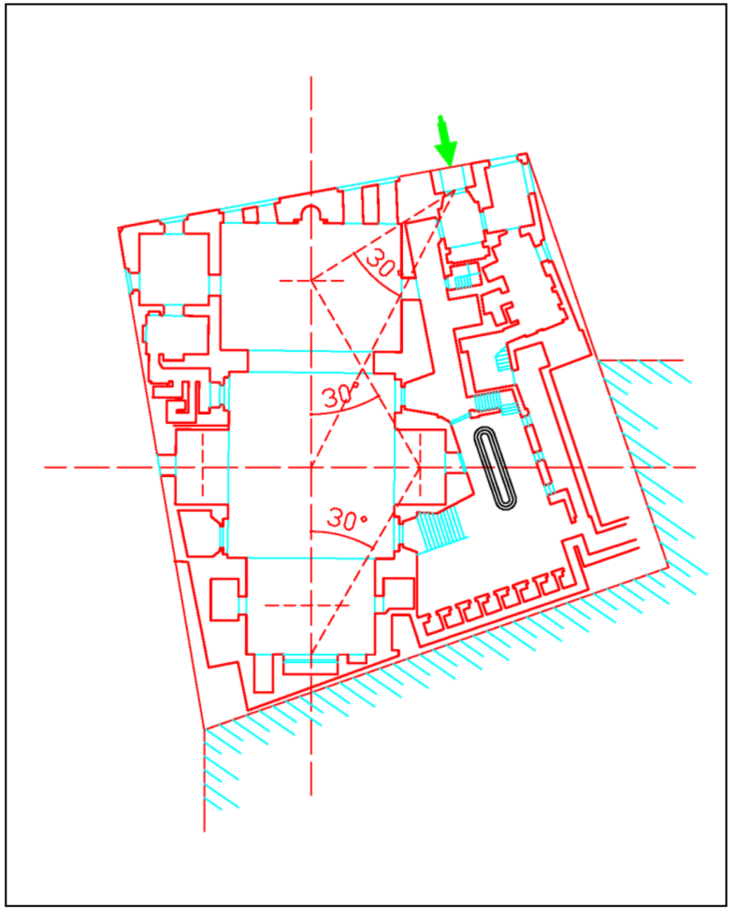


Figure 5-49: The final plan of Madrasa of Sultan Barsbay with the hidden geometric design system

10- Generating the Final Building Plan

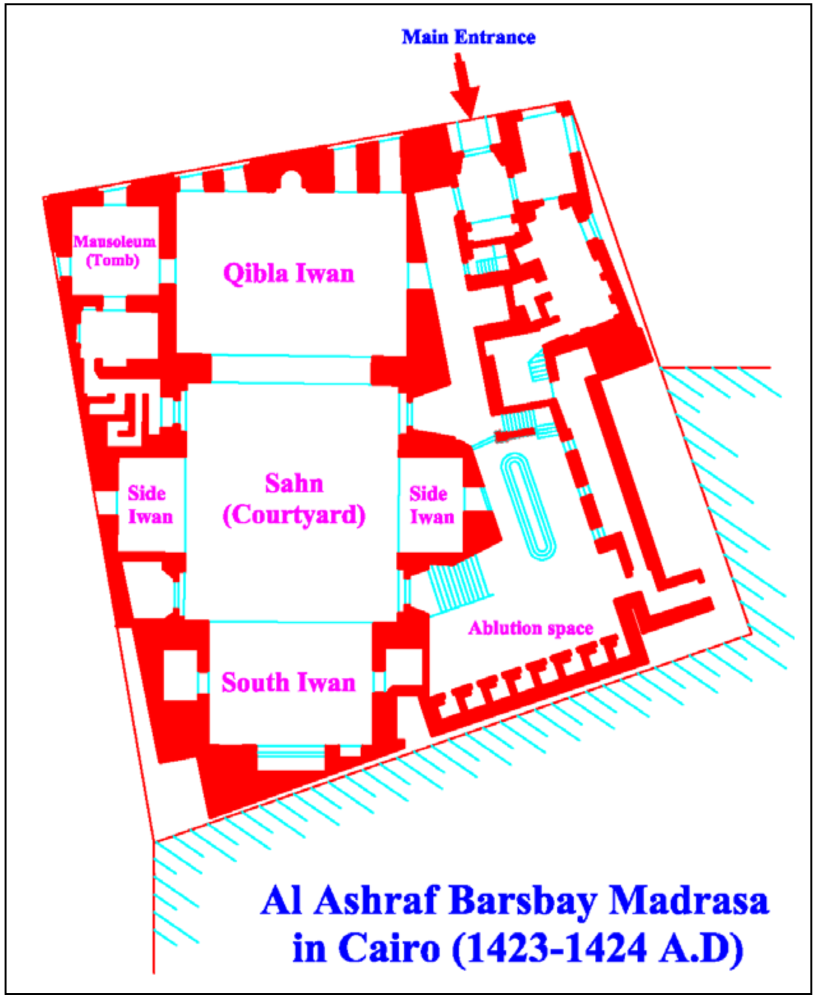


Figure 5-50: The final plan of Madrasa of Sultan Barsbay

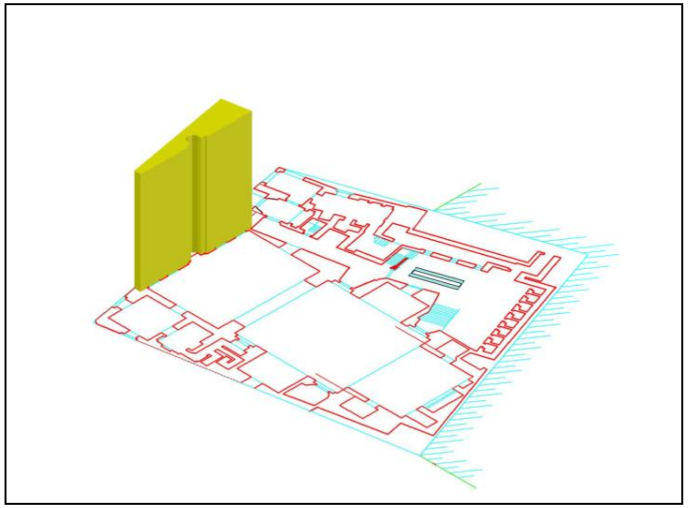
<u>5- Fifth Step:</u> Applying the Interior Space Design Rules.

These are the results of applying the interior space design rules in Madrasa of Sultan Barsbay:
* The qibla wall is square shaped and its height is equal to the building's total height.
* The Four iwans are roofed and their height is equal to the building's total height.
* The Entrance spaces are roofed and their height is equal to the building's total height.
* The design follows the opened courtyard type.

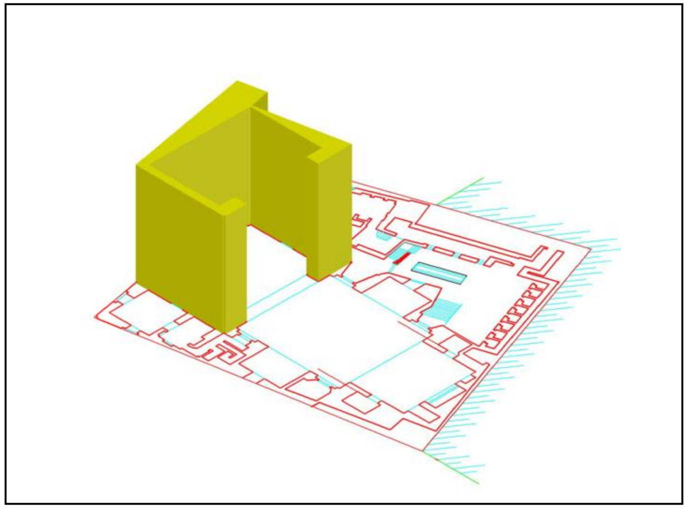
From the interior space design rules the designer can determine the total height of the building, and this is the first step to convert the two-dimensional plans which he had designed into three-dimensional spaces.

<u>6- Sixth Step:</u> Generating the Building Spaces' Disposition (the design of the building in 3D).

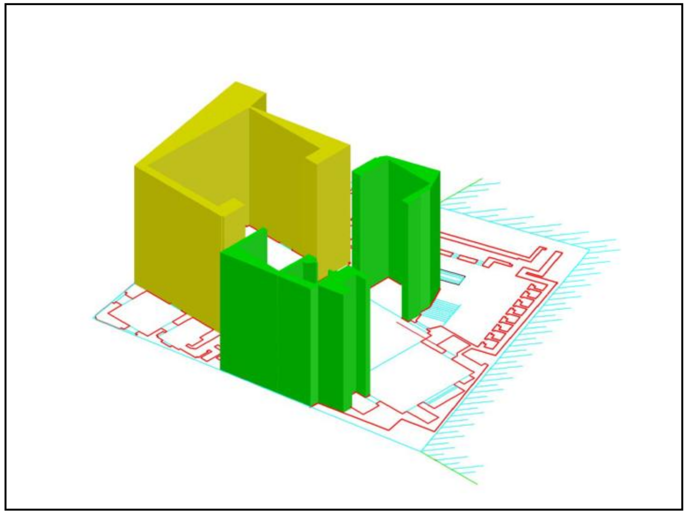
1- Constructing the Qibla Wall



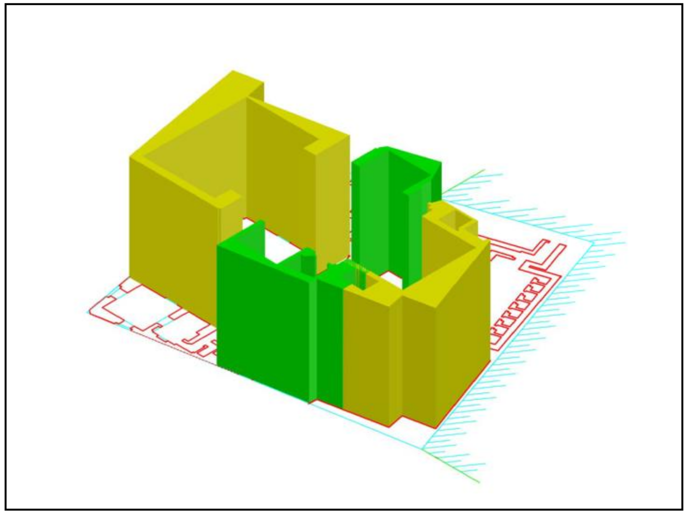
2- Completing the Qibla Iwan



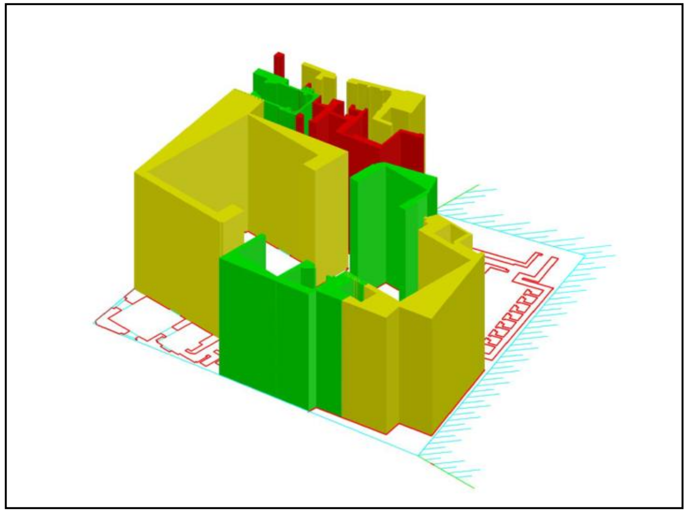
3- Constructing the Side Iwans



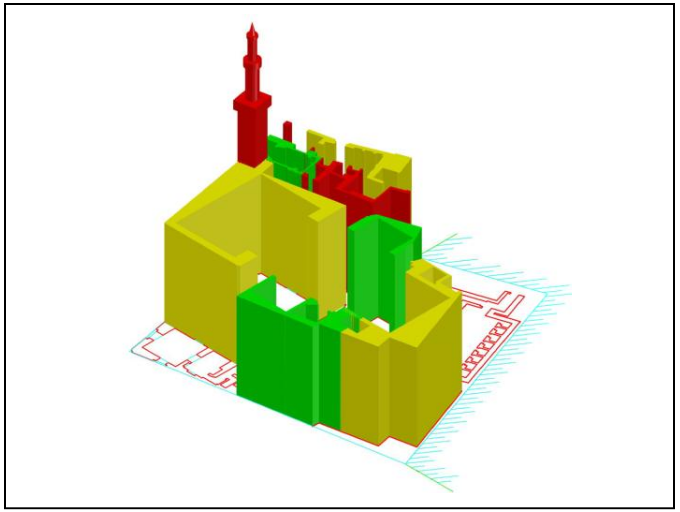
4- Constructing the Sahn and the South Iwan



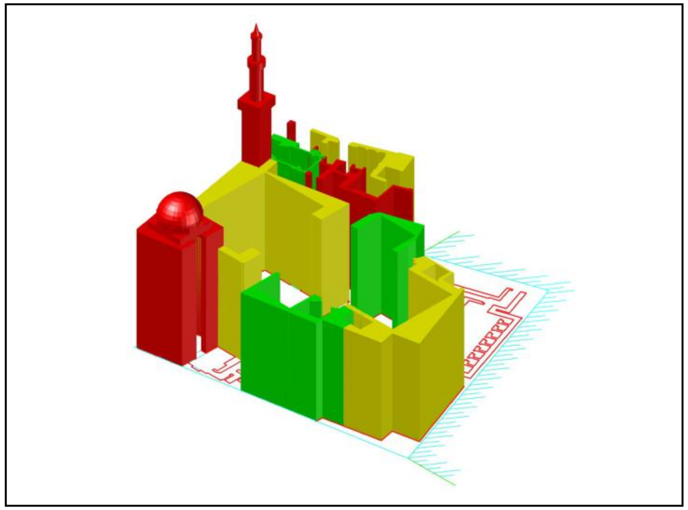
5- Constructing the Entrance and its Cells



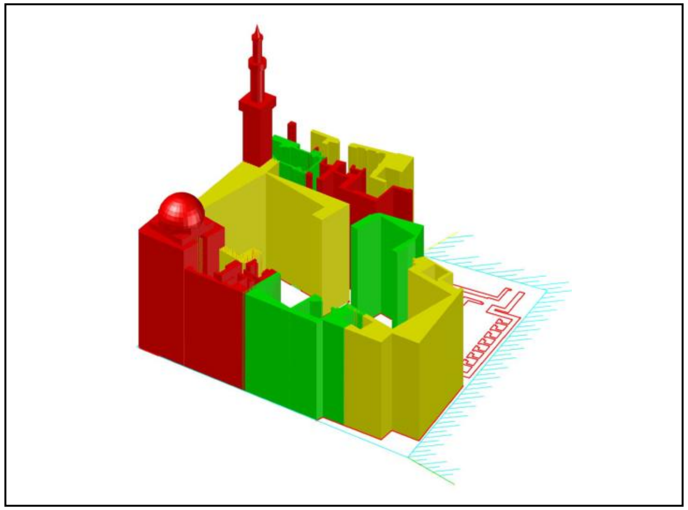
6- Constructing the Minaret



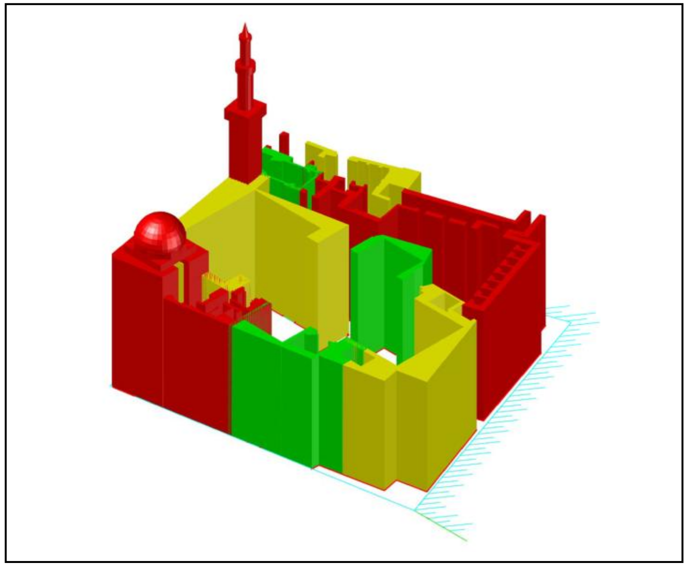
7- Constructing the Mausoleum Main Space



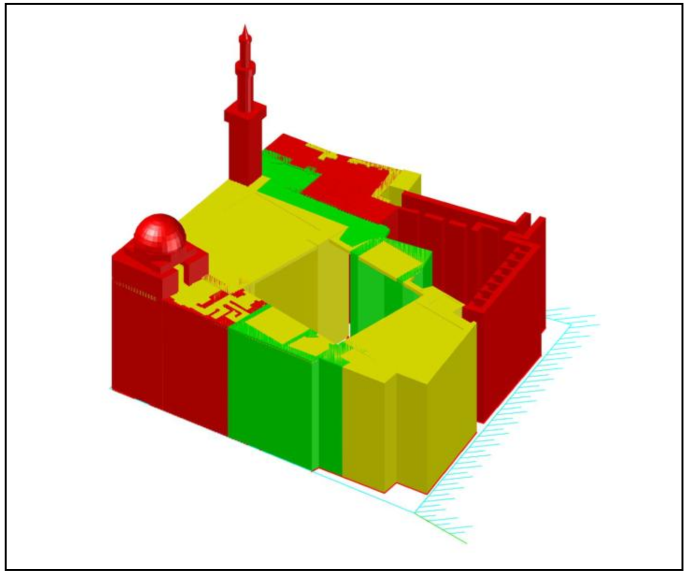
8- Completing the Mausoleum



9- Constructing the Ablution Space



10- Roofing the Building



5.2.1.5 Madrasa of Sultan Qaytbay (1472-4 A.D.)

1- General Description

Although the foundation text refers to the building as a madrasa, the document has specified the function as a khanqah for forty poor (sufis), besides being a congregational mosque.

This building was founded by Sultan king al-Ashraf Abu al-Nasr Qaytbay al-Jarkassy, who assumed power in 1467 A.D., and included a madrasa and a mausoleum for himself and his family. It is located in the Mamluks' desert qarafa (cemetery).

Variant Names	* Madrasa of Sultan Qaytbay, * Mosque-Madrasa of sultan Qaitbay, * Madrasa, Mausoleum, Sabil-kuttab and Rab' of Sultan Qaytbay, * The funerary complex of Sultan Qaytbay * Sultan Ashraf Qaytbay, * Maq'ad of Sultan Qaytbay (Qayt Bay, Kait Bey, Qait Bay), * Mausoleum of al-Gulshani and Sabil-Bab al-Jindi
Street Address	Northern Cemetery
Location	Cairo, Egypt
Date	15^{th} (1472-1474 A.D.)
Style/Period	Mamluk (Circassian)
Building Types	Complex (Educational, Funerary, Religious)
Building Usage	Madrasa, Mausoleum, Sabil.

Table 5-5: The general description of Madrasa of Sultan Qaytbay

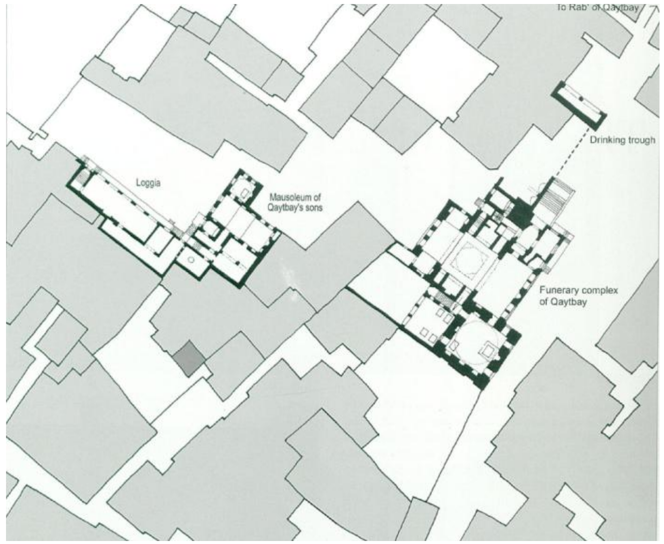


Figure 5-51: The site of Madrasa of Sultan Qaytbay

2- Architectural Description

a- The Layout

The madrasa is composed of a central covered durqa'a surrounded by two iwans and two small side iwans. The qibla iwan consists of a rectangular area overlooking the durqa'a through a pointed arch supported on a stalactitic cantilever.

The plan of the madrasa also includes a sabil, a kuttab and a dome. The sabil and kuttab (Elementary School) occupying the corner of the building in an integral architectural mass directly in contact with the entrance vestibule, while the mausoleum occupies the other corner of the building adjacent to the qibla iwan.

b- The Plan

It is noticed that, in general, the plan followed the common pattern of Mamluk madrasas as far as the composition of elements and its relation with one another is concerned. For instance, we find that of the four iwans the largest is the qibla iwan and the one opposite to it, while the two other side iwan are smaller in size. There are four doors adjacent to the iwans which open on the durqa'a, connecting the madrasa to the other elements of the building and the bent entrance which lead to the study iwans across a corridor that has the drinking space.

By studying and analyzing the internal configuration we find that it depends on similarity in arrangement of openings, either for windows or wall cupboards. The internal heights have varied according to the function of each element, which reflect the relationship between the section and plan. Furthermore, it is noted in the internal space formation the accentuation upon the mihrab and the axis perpendicular to it, as the qibla iwan and the iwan opposite to it are opened to the courtyard through an arch, while the two side iwans open on the courtyard through a stilted pointed arch.

Figure 5-52: The main facade in Madrasa of Sultan Qaytbay

c- The facade

Upon analyzing the external facades we find that its configuration depends on the use of vertical rectangular niches crowned by stalactites and in which upper and lower bays are arranged according to the architectural elements, surrounded by arrow of leaf-shaped cresting, common for Circassian Mamluk buildings.

Elements of the plan can be outlined from the facade through the variety and shape of the window openings which reflect sincerity in expression the interior and the organic relationship between the plan and the facade, as shown in Fig. (5-52).

The elaborate portal has a groined vaulted trilobe recess with Ablaq masonry and carved muqarnas, as shown in Fig. (5-53).

The position of the entrance is accentuated by the method followed in the Circassian Mamluk architecture and by using the same elements. The entrance is situated on the eastern side of the north-eastern facade; it lies in a deep recess with two sitting decks on its sides. Following the entrance is a vestibule which is a rectangular area with a sitting deck at the forefront, and on each side there are two doors, the right one leading to across a corridor to the durqa'a, and the left leading to the sabil.

Figure 5-53: The entrance in Madrasa of Sultan Qaytbay

d- The Minaret

The minaret is a jewel of late Mamluk architecture and carved masonry; a twisted band surrounds the neck of the bulb like a necklace. The minaret is placed on the right jamb of the entrance as a distinguished landmark, as shown in Fig. (5-54), and the base of the minaret protruded a little from the facade's alignment to ensure the continuity of the minaret and its support on the ground instead of its appearance as though it was carried on the roof of the building.

e- The Mausoleum

The mausoleum protrudes into the street on the southeastern corner of the mosque, adding a third facade to the mausoleum, thereby increasing its visibility from the north and adding light to the interior through the pair of superimposed windows in its northern projection. The mausoleum, protruding beyond the northwestern corner of the hall, is roofed with a small masonry dome carved with arabesques.

The dorm's design turns upside down the concept initiated in Barsbay's star domes. Here the design is conceived around a central star that radiates from the apex down to the base, instead of a row of stars departing from the base towards the apex The entire transitional zone of the dome, which is at least as high as the cylindrical section of the dome before it curves, is framed with a carved molding that underlines its composition. The undulating Steps al the corners are beautifully carved, as shown in Fig. (5-56).

The exterior of the complex's stone dome is decorated with a carved straight-lined star pattern superimposed on another carved network of undulating arabesques. The contrasting effect is amplified by treating the surface of each of the two systems differently.

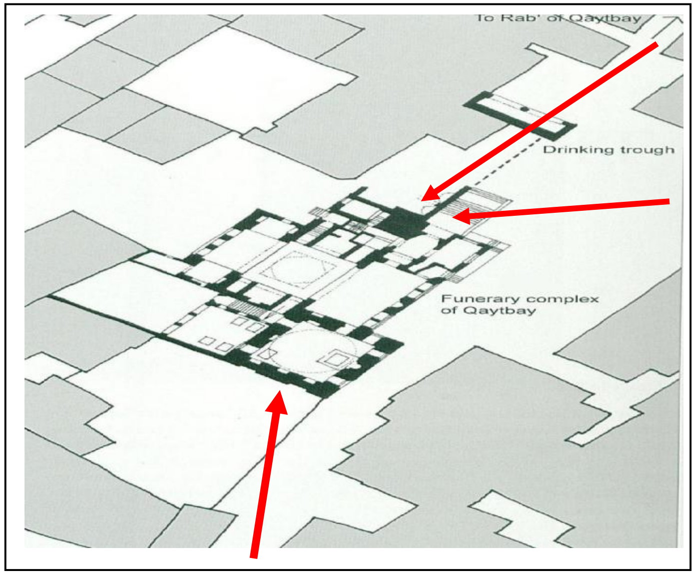


Figure 5-54: The position of the minaret and dome in Madrasa of Sultan Qaytbay

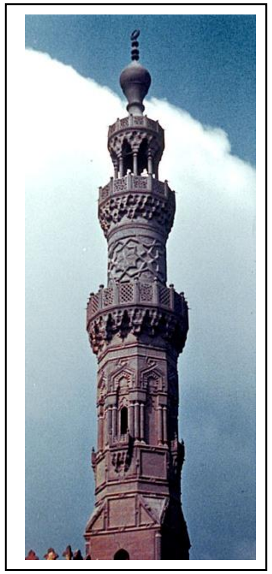


Figure 5-55: Exterior detail of the minaret in Madrasa of Sultan Qaytbay

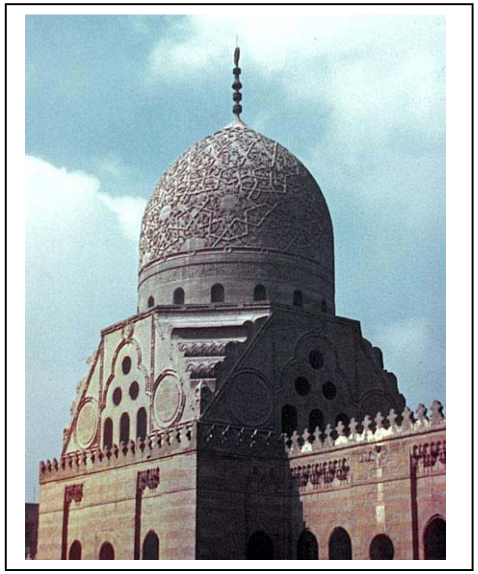


Figure 5-56: The mausoleum dome in Madrasa of Sultan Qaytbay

3- Applying the Geometric Generative Technique:

The different steps of the geometric generative technique will be applied in Madrasa of Sultan Qaytbay.

Pre-Design step:

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building's entrance so that it is in relation to the minaret to make some kind of visual emphasis to the building.

b- Study the position of the dome.

The designer chooses the position of the building's dome so that it is plays the role of landmark for the building. He places it in the building corner, as shown in Fig. (5-57).

c- Study the position of the minaret.

The designer chooses the position of the building's minaret so that it is plays the role of landmark for the site, and the pedestrians can see it from a distance, as shown in Fig. (5-57).

Figure 5-57: The position of the dome and the minaret in Madrasa of Sultan Qaytbay

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Fig. (5-58).

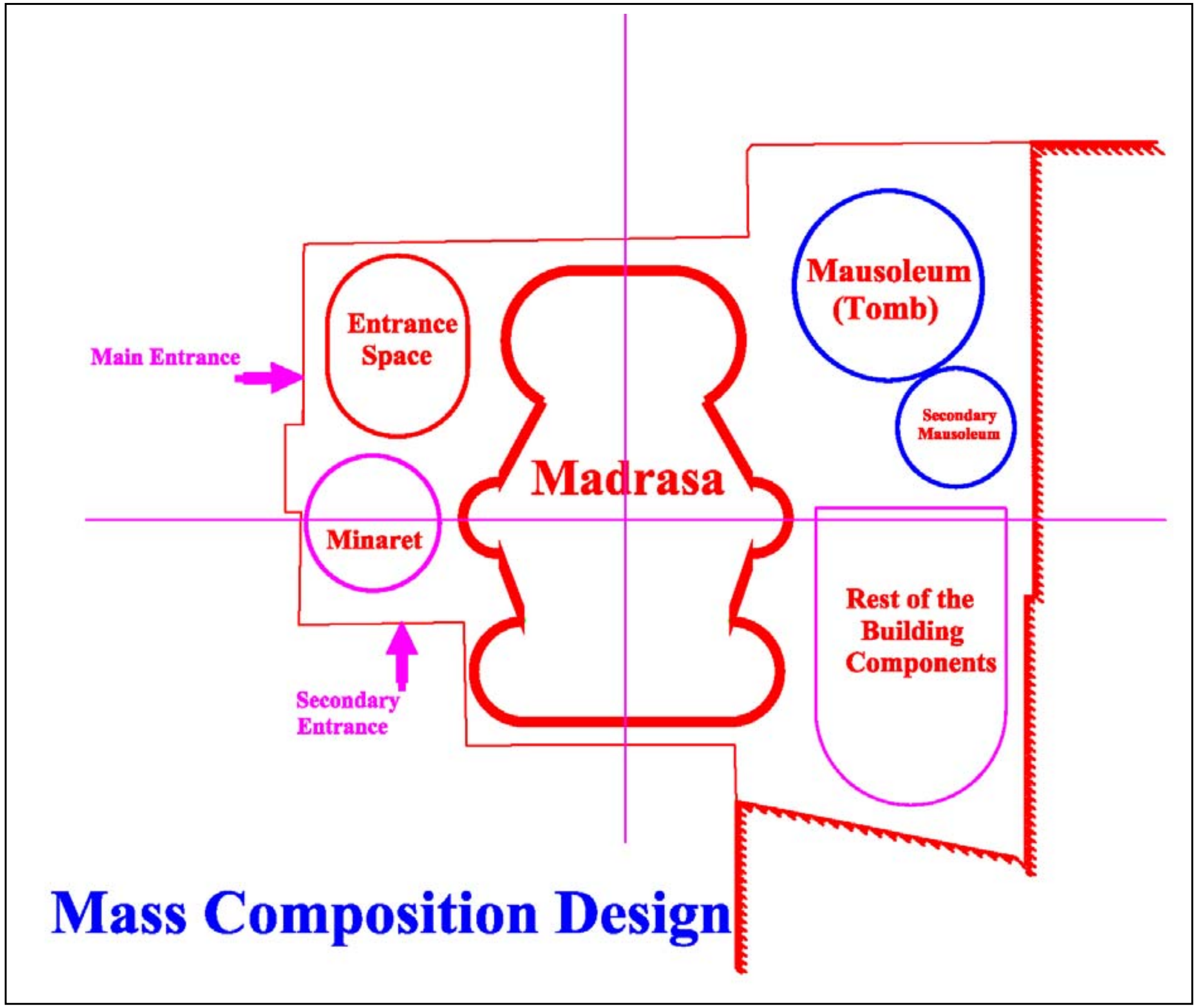
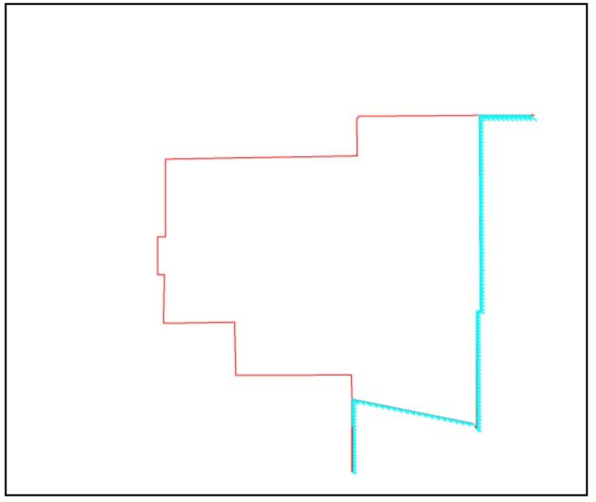
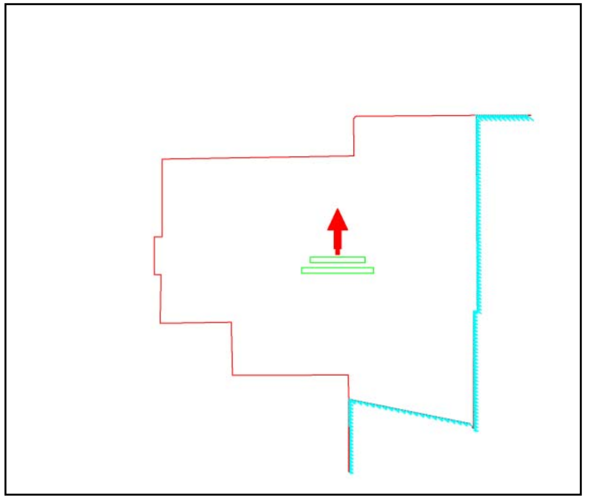


Figure 5-58: The mass composition in Madrasa of Sultan Qaytbay

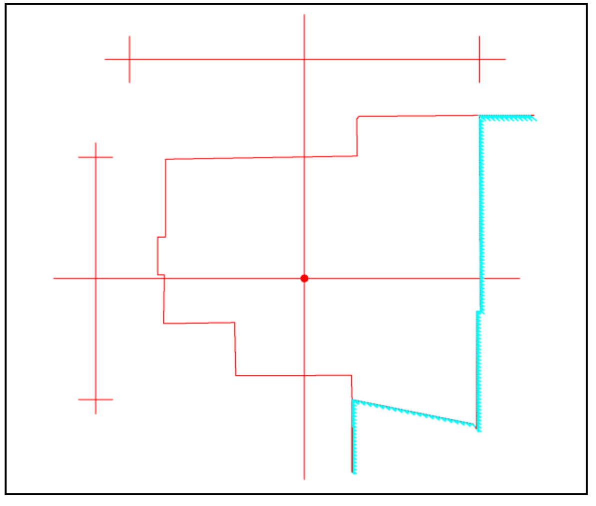
<u>1- First Step:</u> Determining the Site Boundary, the Qibla Direction and the Sahn's Centre Point.



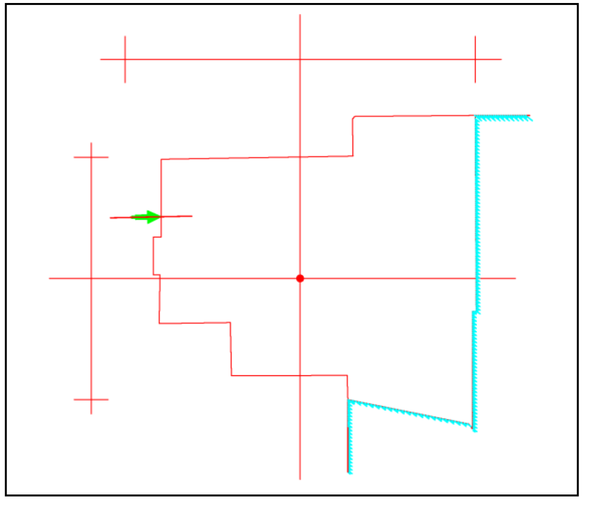
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

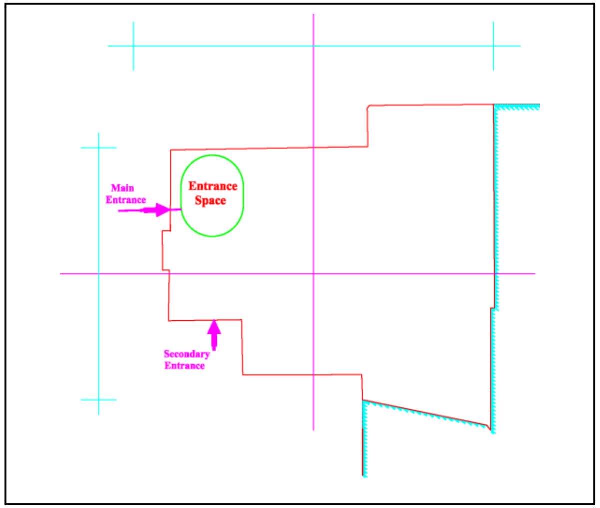


c- Determining the sahn's centre point

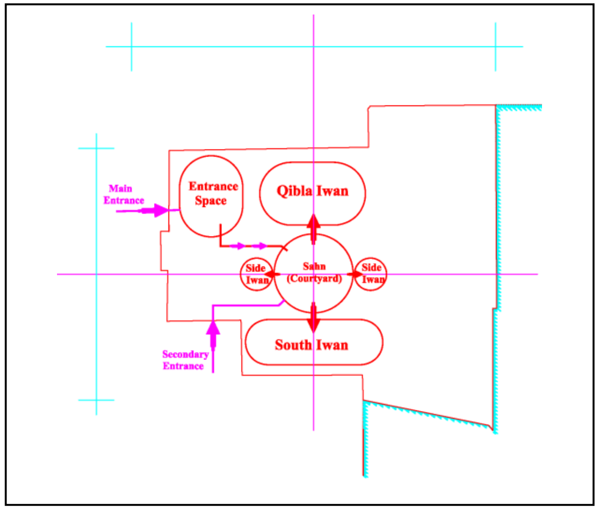


d- Adding the main entrance axis

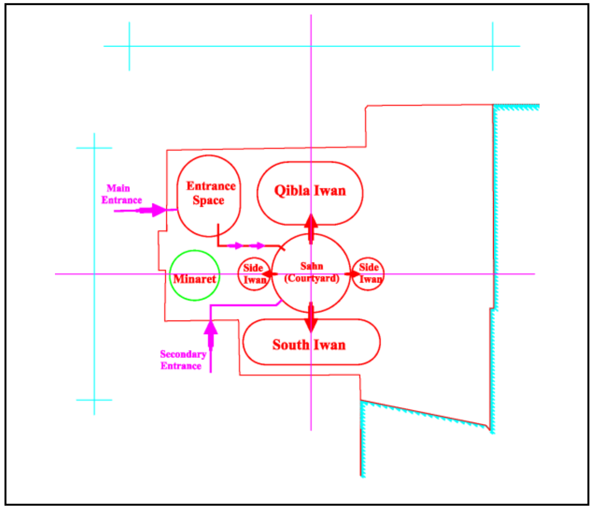
2- Second Step: Determining the Functions' Relationships and the Users' Circulations Diagram.



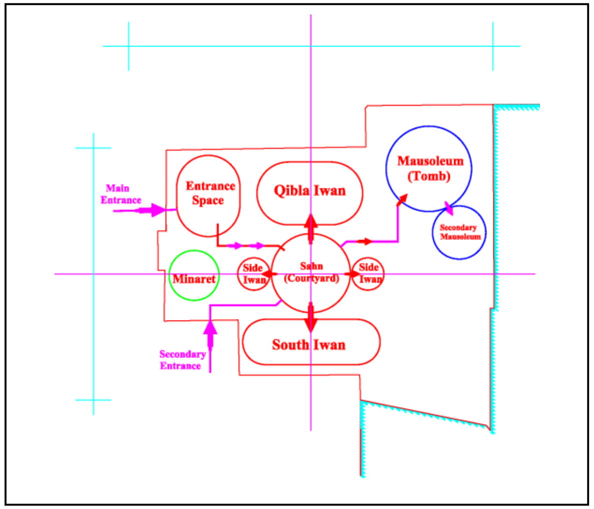
a- Determining the entrances position



b- Determining the position of the sahn and all iwans



c- Determining the minaret position



d- Determining the mausoleum position

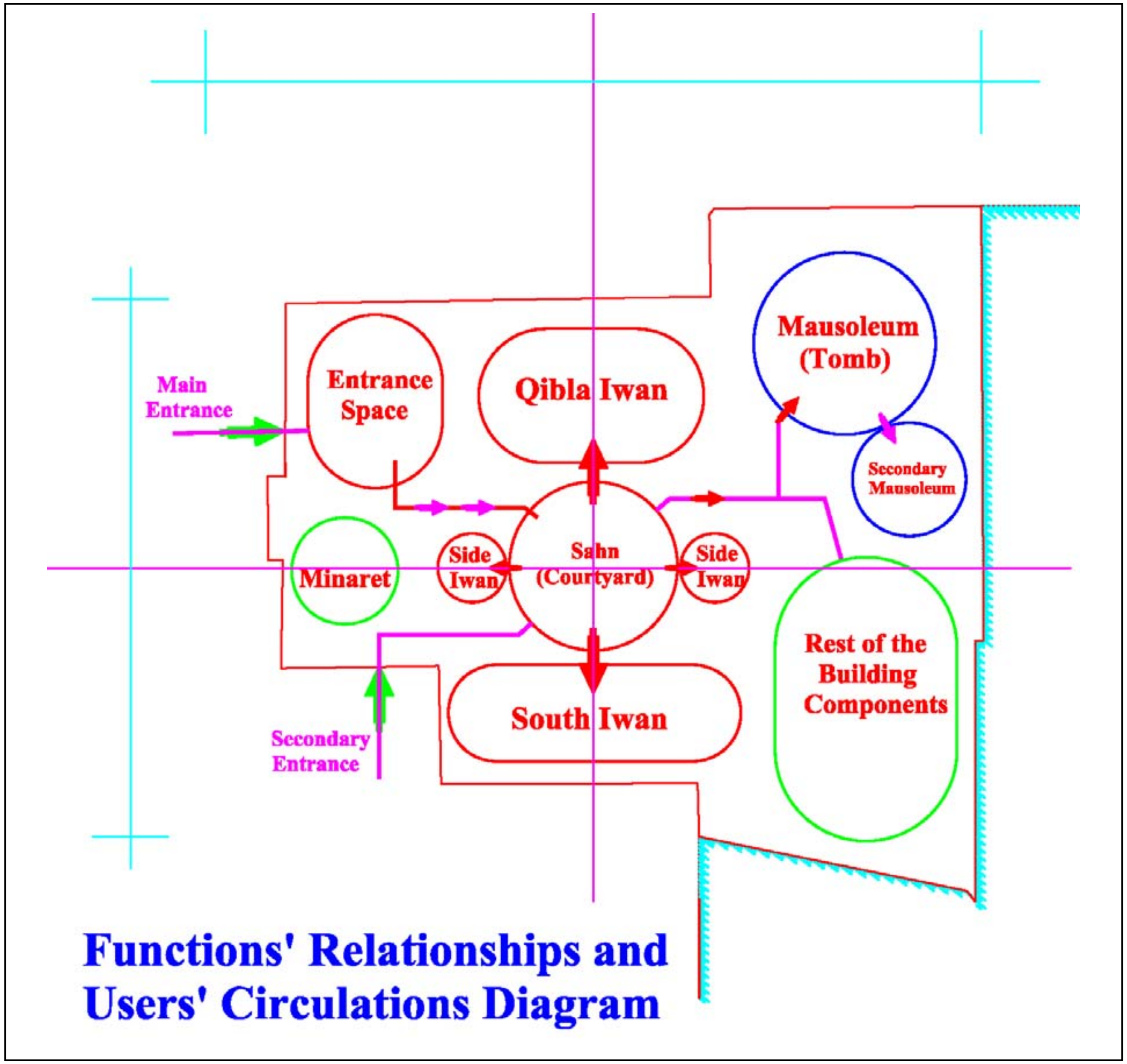
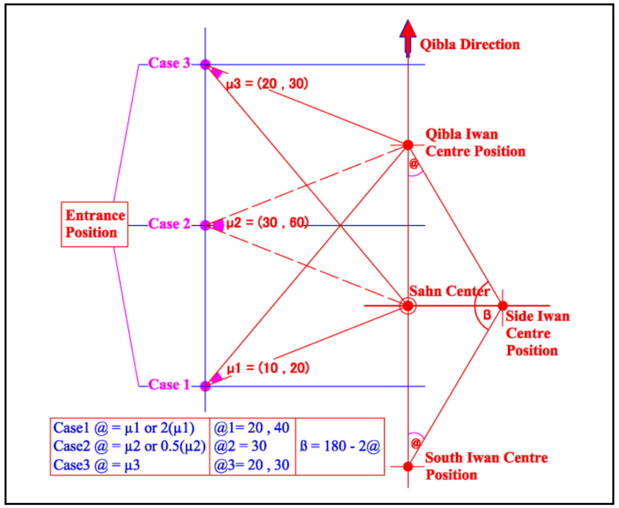
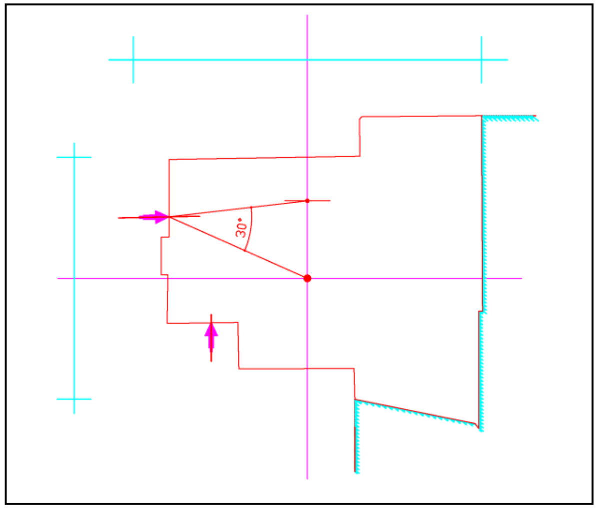


Figure 5-59: The final functions' relationships diagram in Madrasa of Sultan Qaytbay

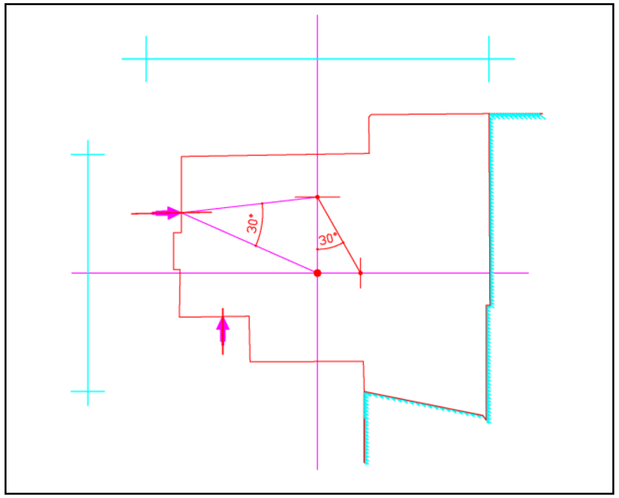
<u>**3- Third Step:**</u> **Applying the Hidden Geometric System** (Determining **μ**, **@** and **ß** angles)



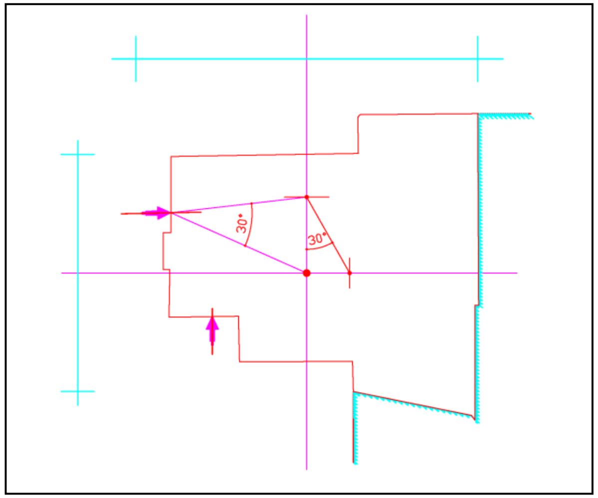
a- The hidden geometric system
(Determining the μ, @ and ß angles)



b- Determining the qibla iwan's centre point
(Applying the μ angle)



c- Determining the side iwan's centre points
(Applying the @ angle)

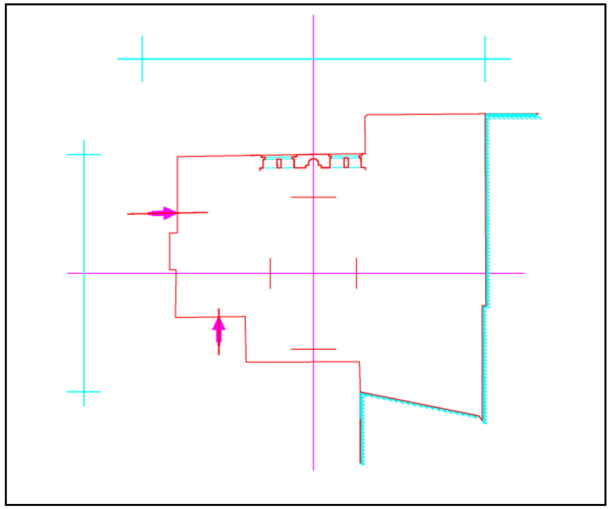


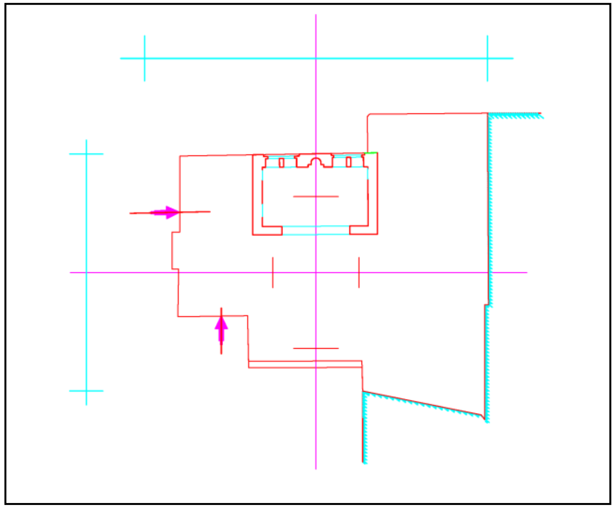
d- Determining the south Iwan's centre point
(Applying the ß angle)

<u>4- Fourth Step :</u>- Generating the Building Plan's Design (the design of the building in 2D).

1- Generating the Qibla Iwan (Praying Hall)

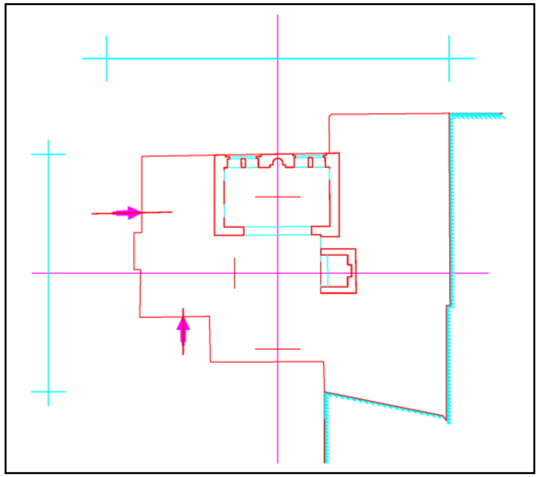
a- Designing the qibla wall



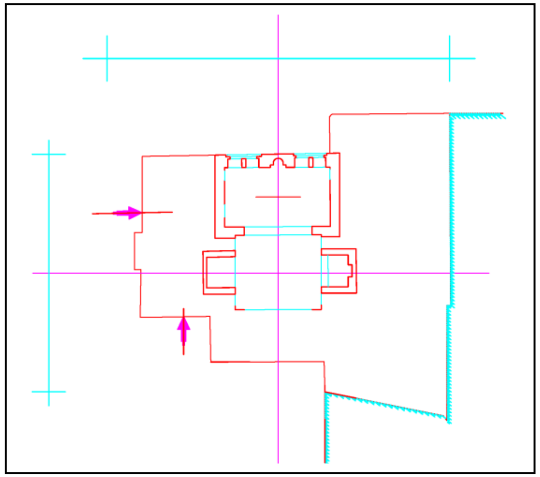


b- Completing the design of qibla iwan

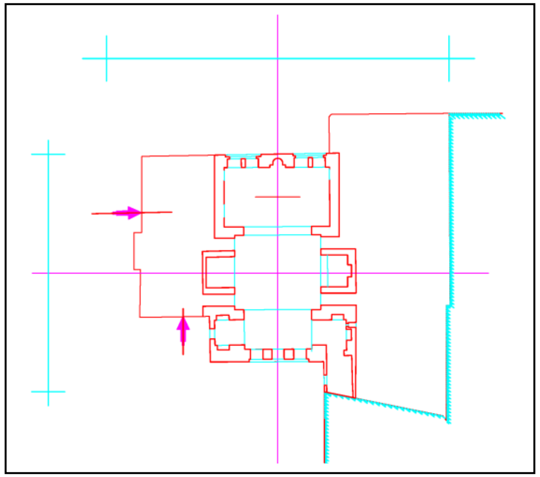
2- Generating the Sahn (Courtyard) and the Two Side Iwans



a- Designing one of the side iwans

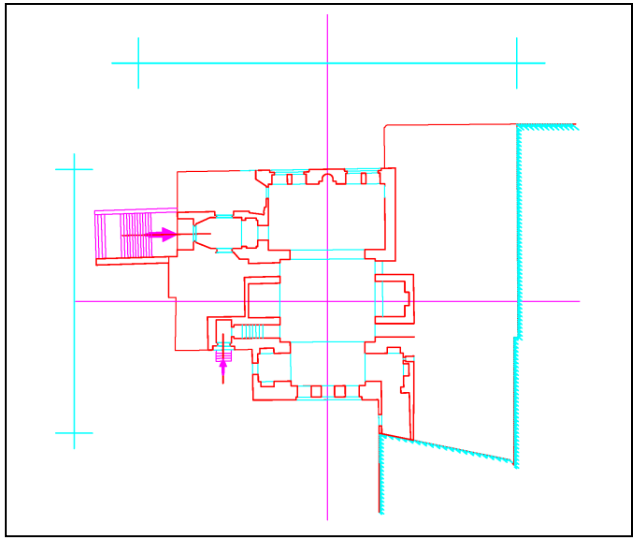


b- Designing the second side iwan

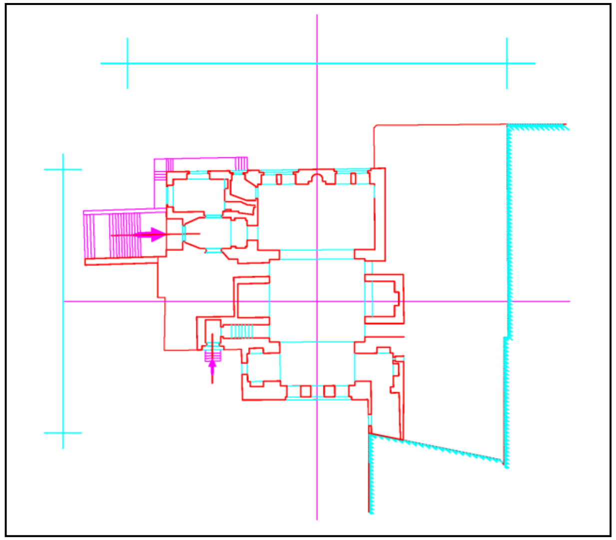


c- Completing the sahn and south iwan design

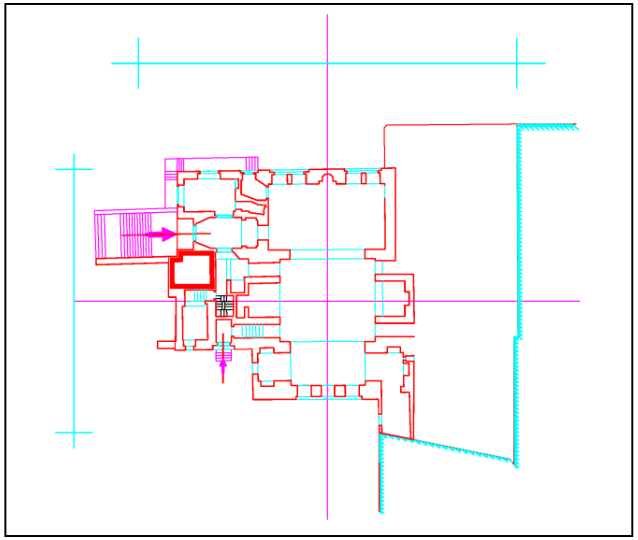
3- Locating the Entrance Design



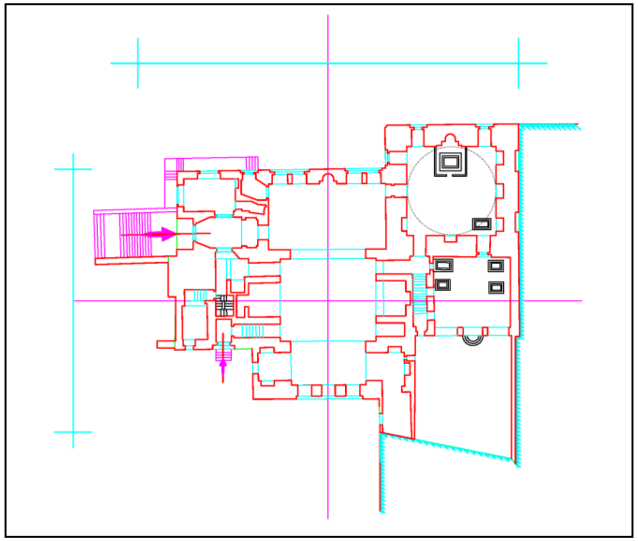
4- Determining the Position of the Sabil



5- Determining the Position of the Minaret



6- Determining the Position of the Mausoleum



7- The Final Building Plan with the H.G.D. system **8- Generating the Final Building Plan**

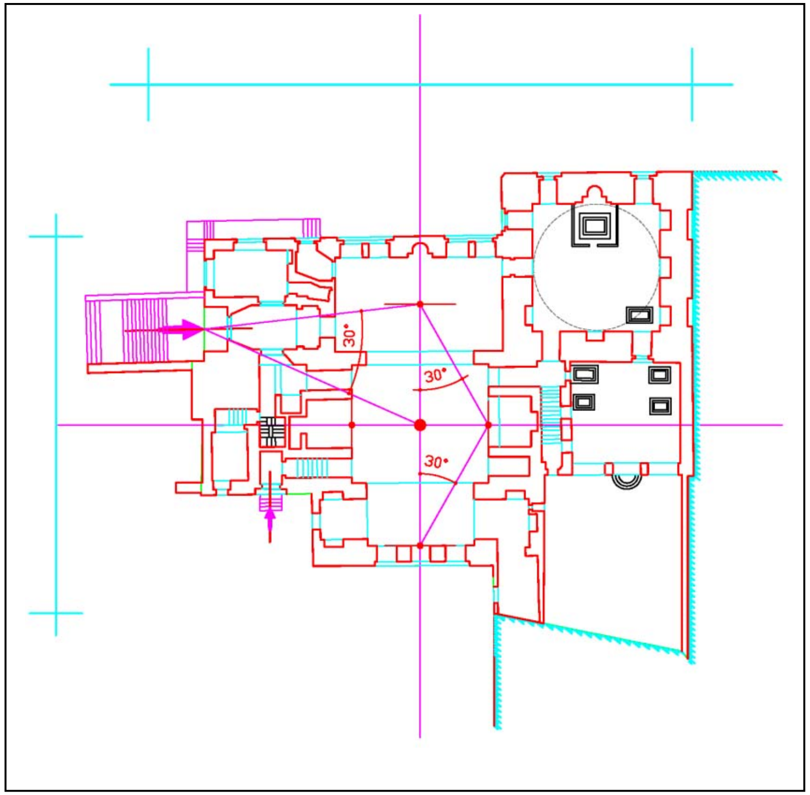


Figure 5-60: The final plan with the hidden geometric design system in Madrasa of Sultan Qaytbay

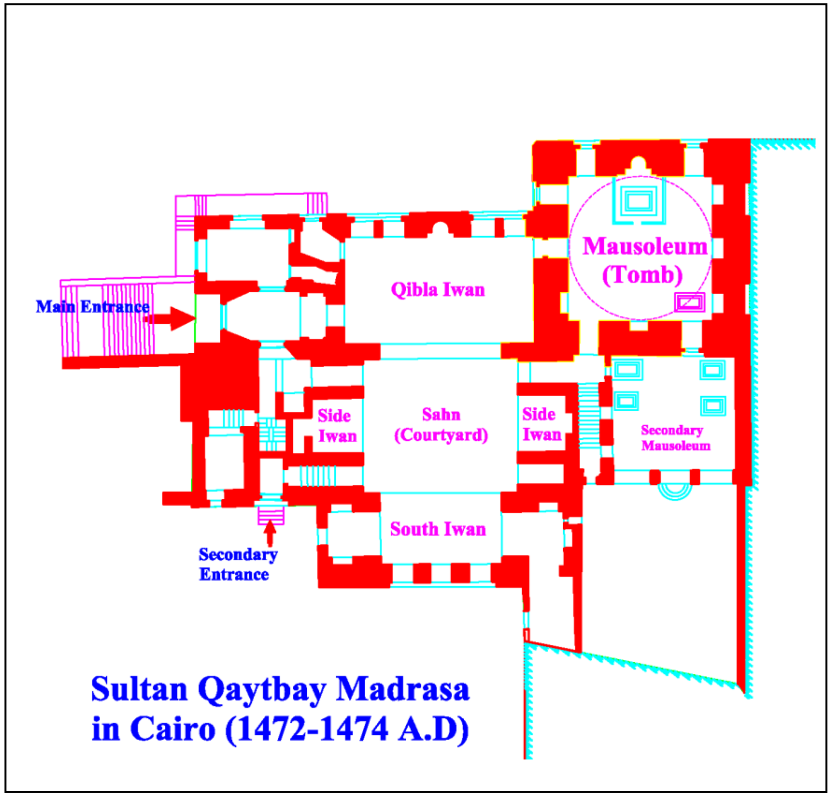


Figure 5-61: The final plan of Madrasa of Sultan Qaytbay

<u>5- Fifth Step:</u> Applying the Interior Space Design Rules.

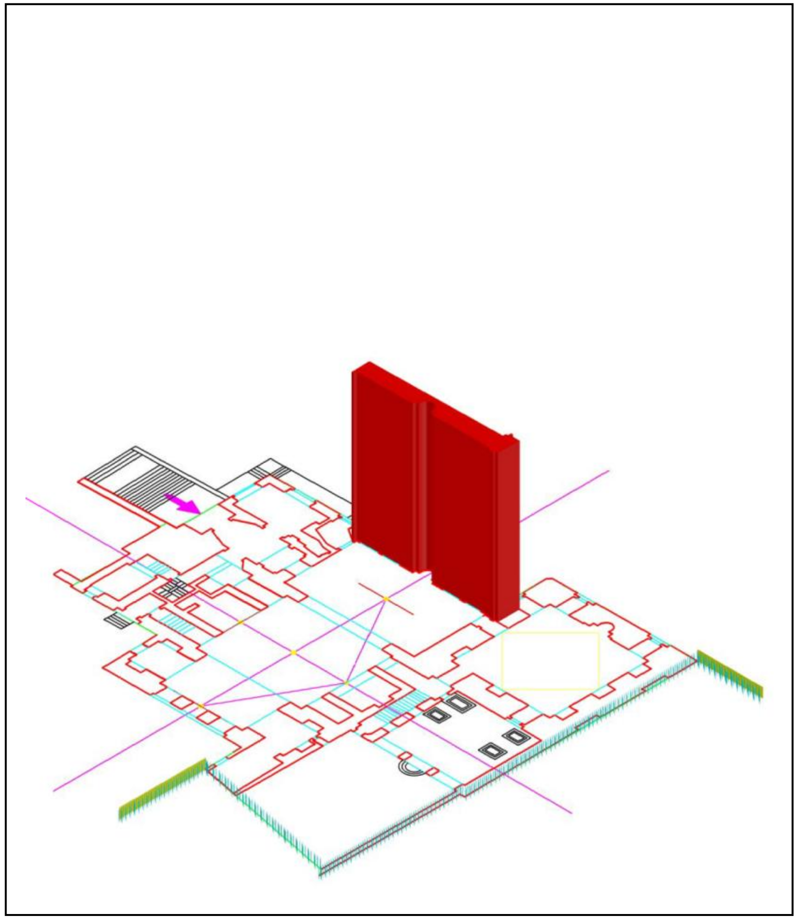
These are the results of applying the interior space design rules in the Um al-Sultan Sha'ban Complex building:

* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.

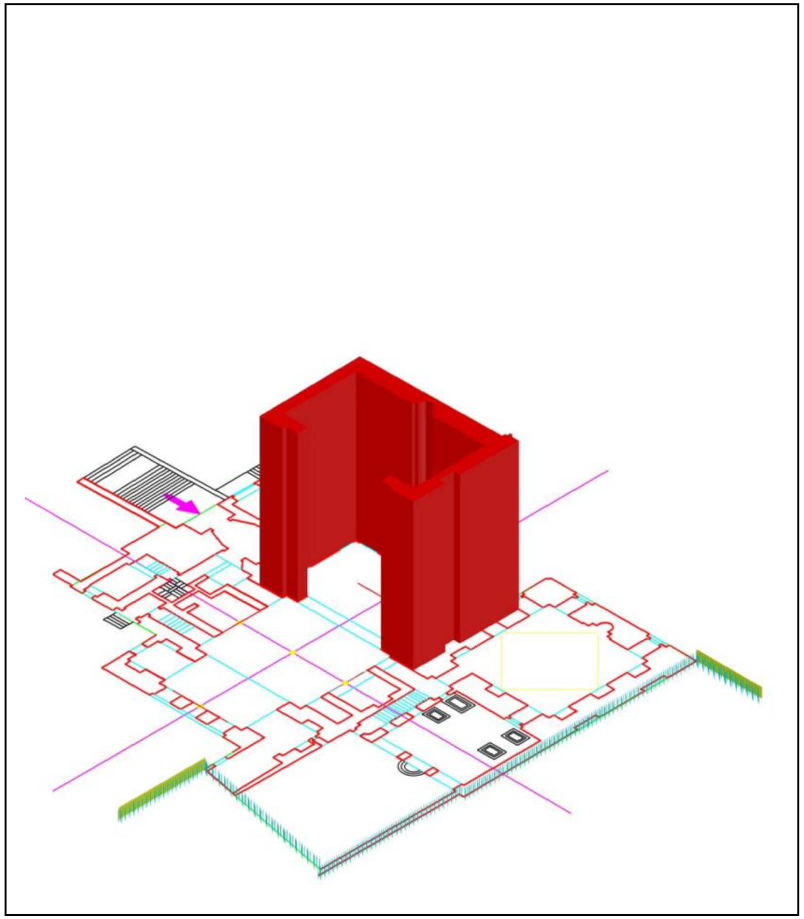
* The entrance spaces are roofed and their height is equal to the building's total height.
* The design follows the roofed courtyard type.
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans which he has designed into three-dimensional spaces.

<u>6- Sixth Step:</u> Generating the Building Spaces' disposition (The Design of the building in 3D).

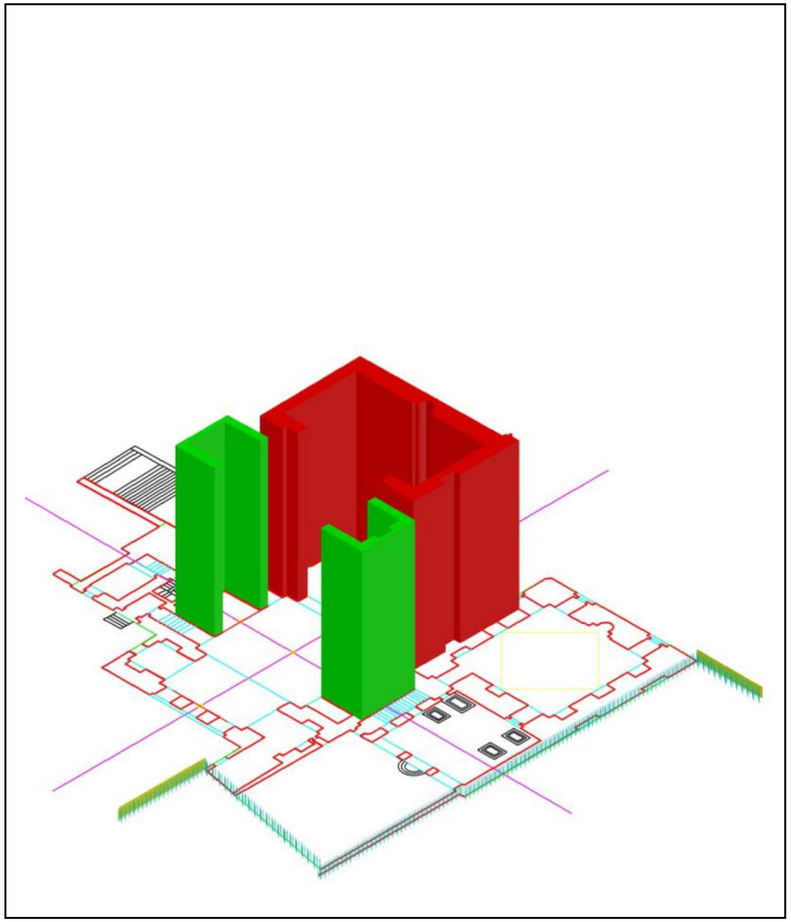
1- Constructing the Qibla Wall



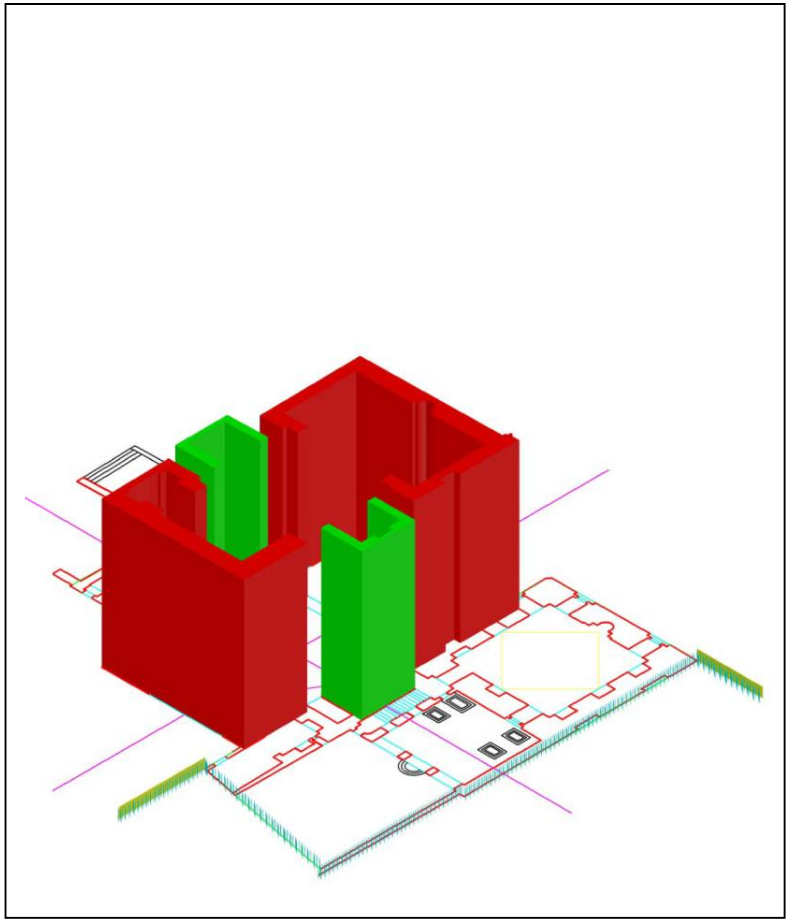
2- Completing the Qibla Iwan



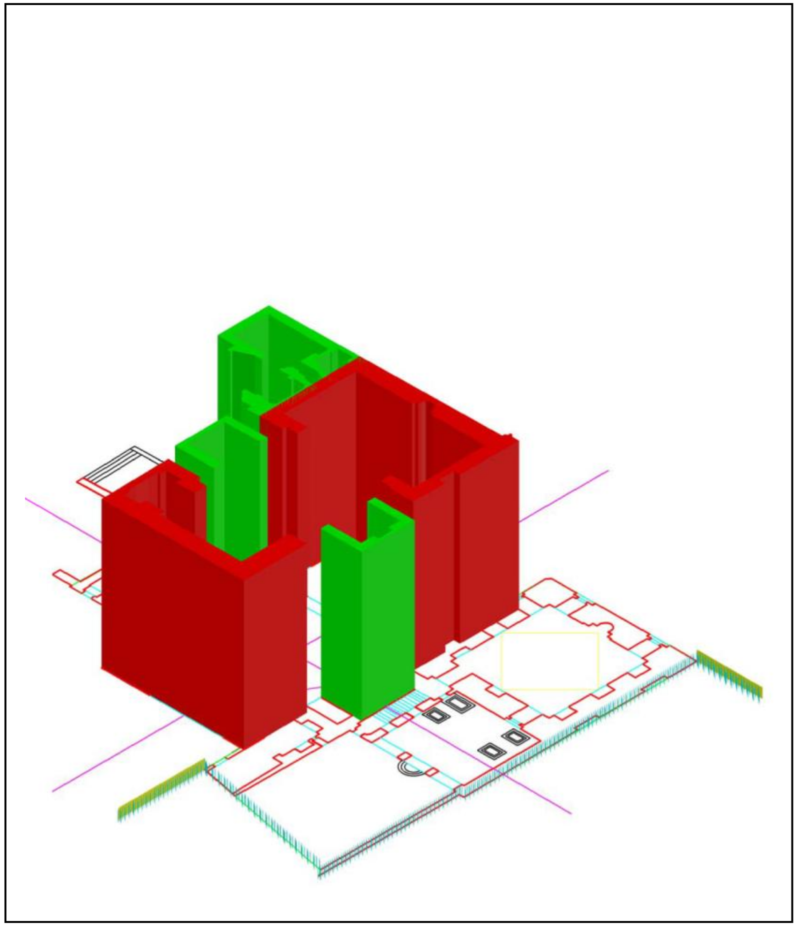
3- Constructing the Side Iwans



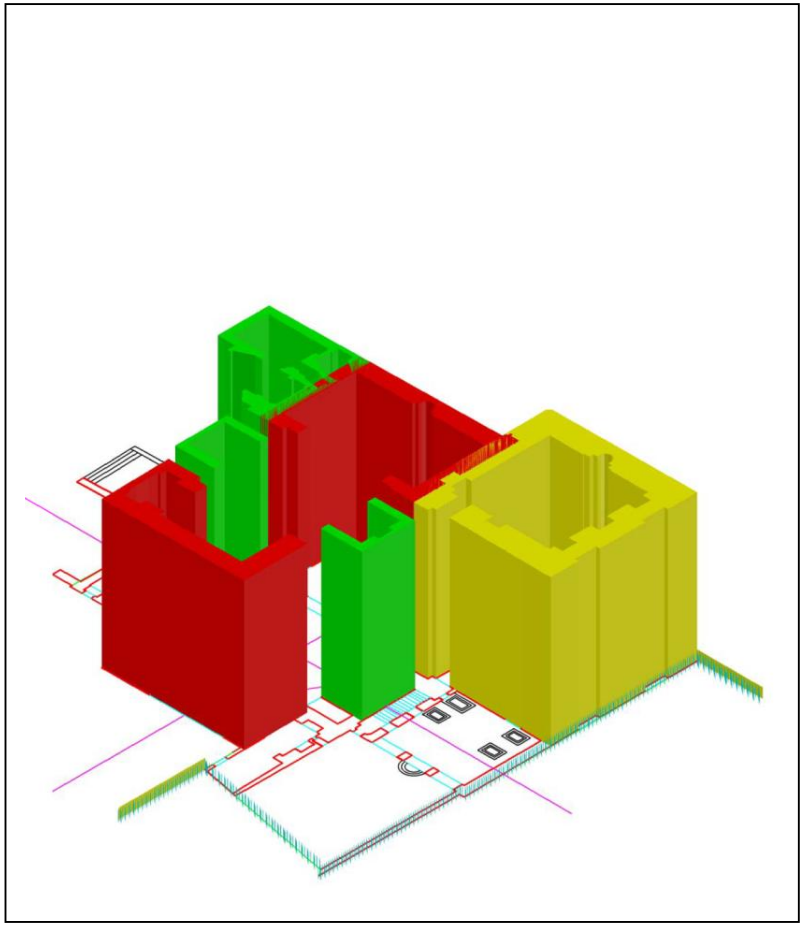
4- Constructing the South Iwan



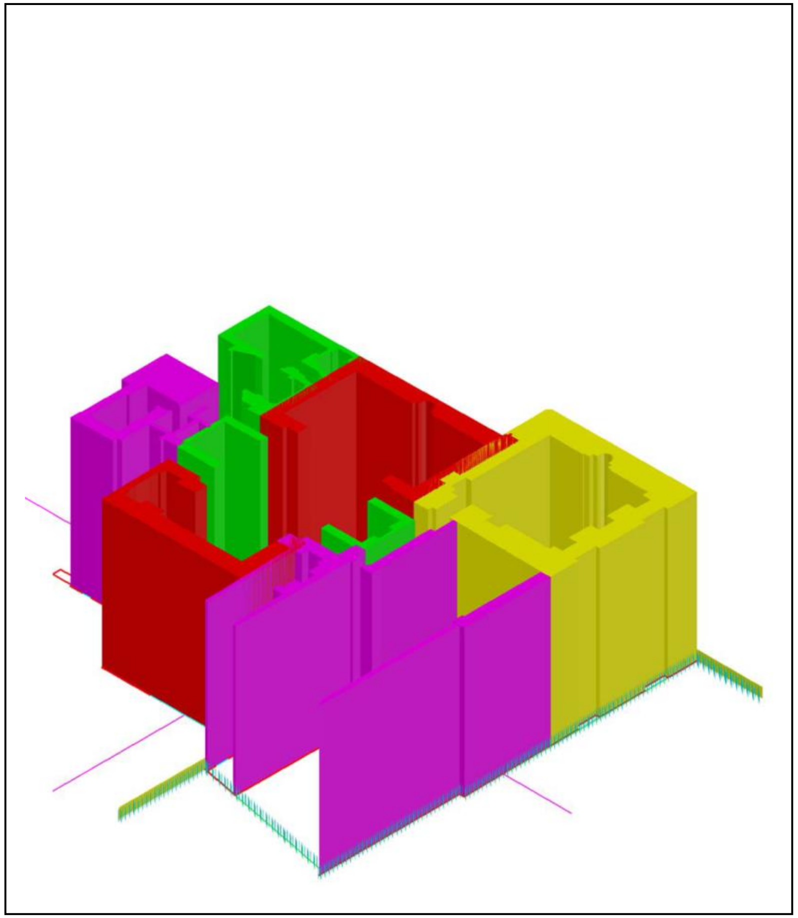
5- Constructing the Entrance and its Spaces



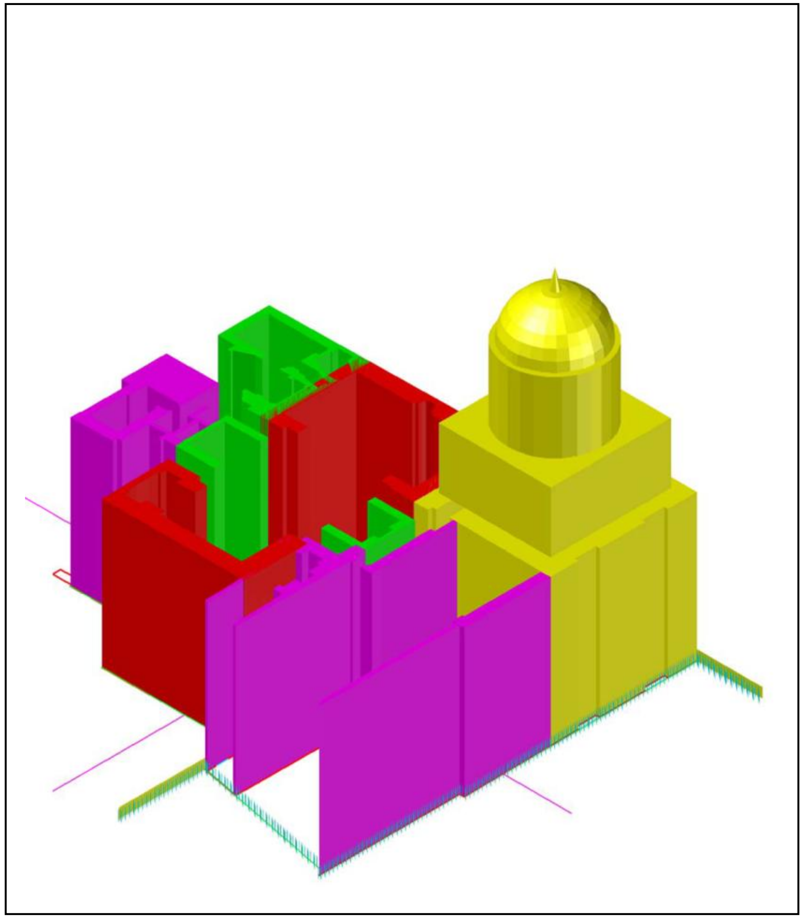
6- Constructing the Mausoleum



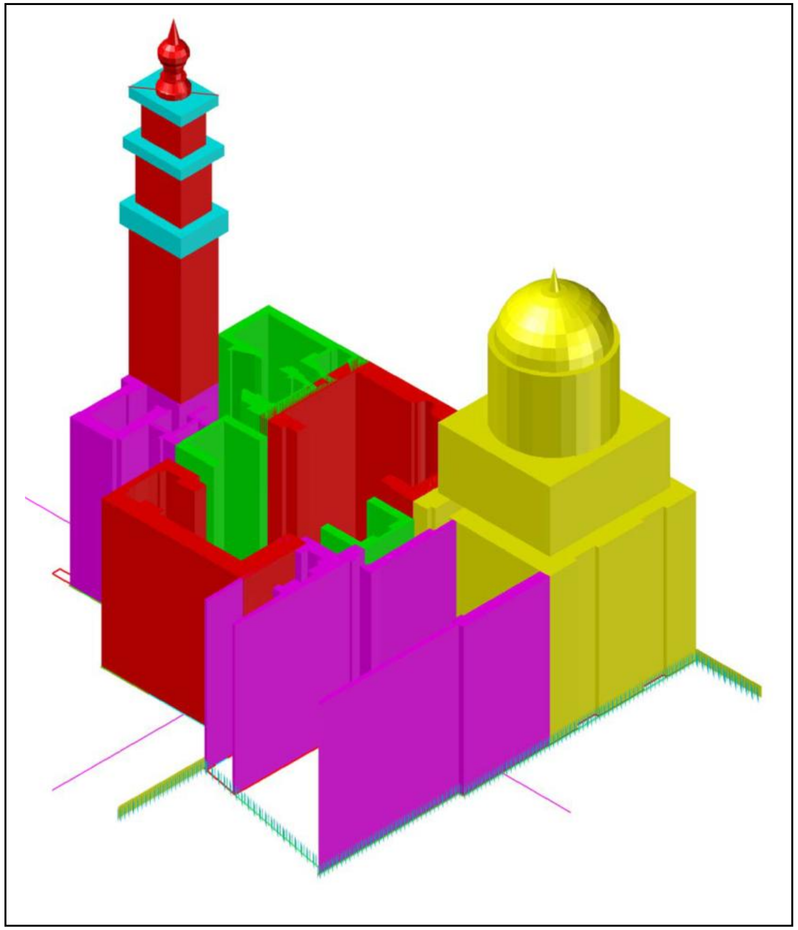
7- Constructing the Rest of the Building's Spaces



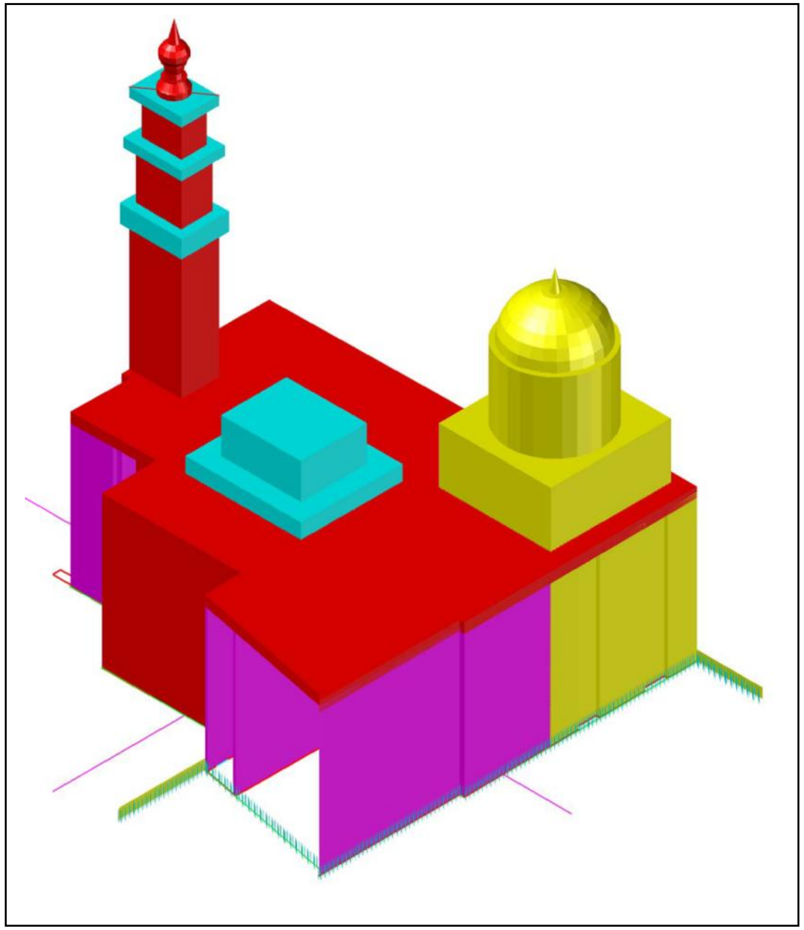
8- Constructing the Mausoleum's Dome



9- Constructing the Minaret



10- Roofing the Building



5.2.1.6 Madrasa of Qadi Abu Bakr Muzhir (1479-80 A.D.).

1- General Description

The madrasa is one of the remarkable remaining buildings that date back to the age of the Burgi Mamluk period. This madrasa is located in what is now called Harat (lane) Burguwan. Branching from al-Mu'izz Street, the building occupies the corner of two small streets and founded by Zain al-Din Abu Bakr Muhammad ibn Muzhir in 1479 A.D.

Variant Names	* Madrasa of Qadi Abu Bakr Muzhir, * Madrasa of Abo Bakr Ibn Muzhir, * Qadi Abu Bakr Muzhir Complex * Sabil and Kuttab of Qadi Abu Bakr ibn Muzhir
Location	Cairo, Egypt
Date	15th (1479-1480 A.D.)
Style/Period	Mamluk (Circassian)
Building Types	Complex (Educational, Religious)
Building Usage	Madrasa, Mosque, Sabil.

Table 5-6: The general description of Madrasa of Qadi Abu Bakr Muzhir

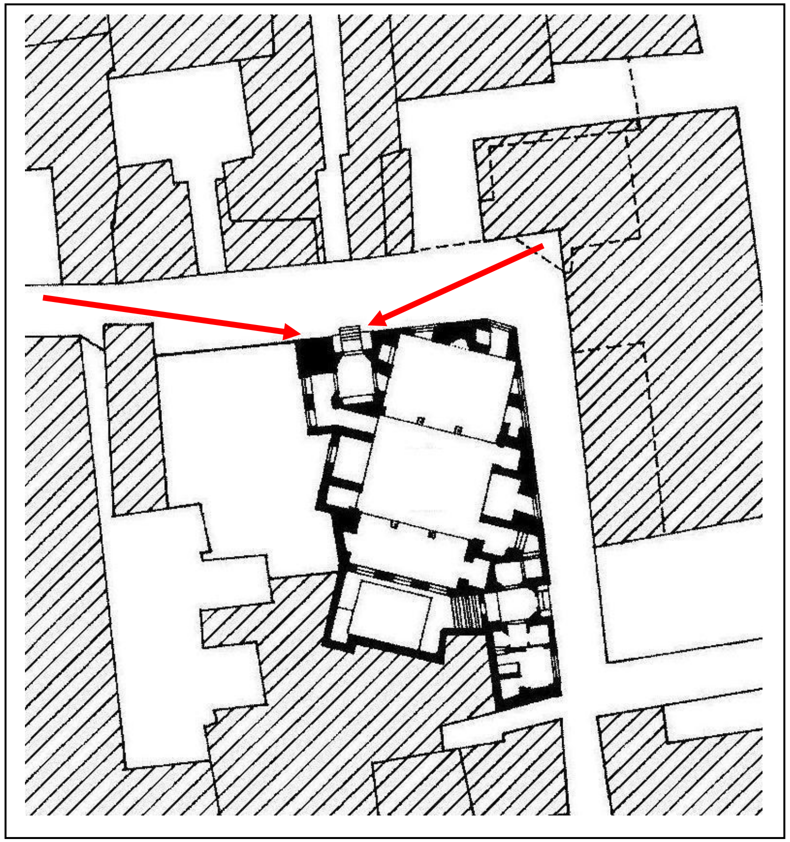


Figure 5-62: The site of Madrasa of Qadi Abu Bakr Muzhir

2- Architectural Description

a- The Layout

The madrasa consists of a covered courtyard, a sabil and a kuttab that occupies the corner of the building next to the secondary entrance, and ablutary placed behind the madrasa in the north-west side. It is representative of the architectural and decorative styles of the period. The sabil lies to the left of the entrance, and on the top of the sabil there is a kuttab.

b- The Plan

The plan is a variation on the qa'a pattern. Rather than the oblong qa'a, its form is almost square, with the two major iwans facing the central space with a triple arch supported by a pair of columns. The western or second iwan includes a recess in its frontal wall, with both iwans opening onto the covered courtyard through a tripartite portico.

c- The facade

The plan respects the direction of the qibla as well as the street line which resulted in the variation of the external walls thickness.

Upon studying and analyzing the external formation of the building, the Mamluk architecture pattern can be seen in the treatment of the external facades, so far as the use of vertical rectangular niches crowned by stalactites and leaf-shaped cresting, and the regular arrangements of the upper and lower openings, as shown in Fig. (5-63). The facades are crowned by stone leaf-shaped cresting, and are characterized by their rich and solemn formations. Using the building materials in their natural form confirmed the building's adaptability to the environment.

d- The Portal

The pattern of bent entrances is used to serve in the gradual movement from outside to the inside a matter that provides a suitably quiet atmosphere for the building. The arched recesses in Abu Bakr's mosque are framed by a molding that runs along the whole of the interior. As on contemporary portals, it is composed of a double band interlocking into loops, like a chain.

It is observed that the madrasa has numerous entrances because of its location at the intersection of two streets which necessitated connecting the madrasa to the surrounding blocks of buildings. There are two entrances due to the madrasa's location on the corner of two streets; the main entrance, above which rises the minaret to its right, opens in the south-east facade which is the qibla iwan's facade. The secondary entrance is located in the western end of the south-west facade.

e- The Minaret

The minaret has a small square base turning into an octagonal shaft, and on its sides are compact columns. On the top of the octagonal shaft are rows of stalactites carrying the first balcony that encircles a circular shaft decorated with geometrical ornaments topped, in turn, by rows of stalactites supporting another circular balcony crowned by the pavilion which is mounted on eight columns, surmounted by an onion-shaped Mamluk dome, crowned by a crescent, as shown in Fig. (5-63).

The beautifully carved minaret, with a star adorning its middle section, stands near the trilobed portal in the eastern facade. The facades are not elaborate, probably due to the location of the building in a side street.

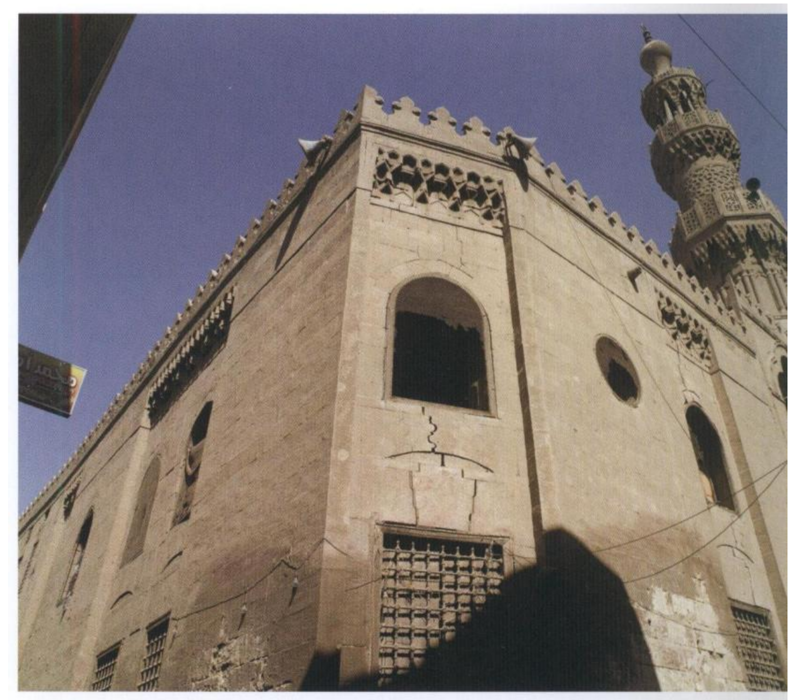


Figure 5-63: The position of the qibla iwan in the building corner and the minaret in Madrasa of Qadi Abu Bakr Muzhir

3- Applying the Geometric Generative Technique:

The different steps of the geometric generative technique will be applied in Madrasa of Qadi Abu Bakr Muzhir.

Pre-Design step:

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Study the building site's urban context.

2- Draw the dialogue between the building and its urban surroundings.

a- Study the position of the entrance

The designer chooses the position of the building's entrance so that it is in relation to the minaret in order to make some kind of visual emphasis to the building, as shown in Fig. (5-62).

c- Study the position of the minaret.

The designer chooses the position of the building's minaret so that it is plays the role of landmark for the site, and pedestrians can see it from a distance, as shown in Fig. (5-62).

3- Suggest the building mass composition.

From the building site's urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Fig. (5-64).

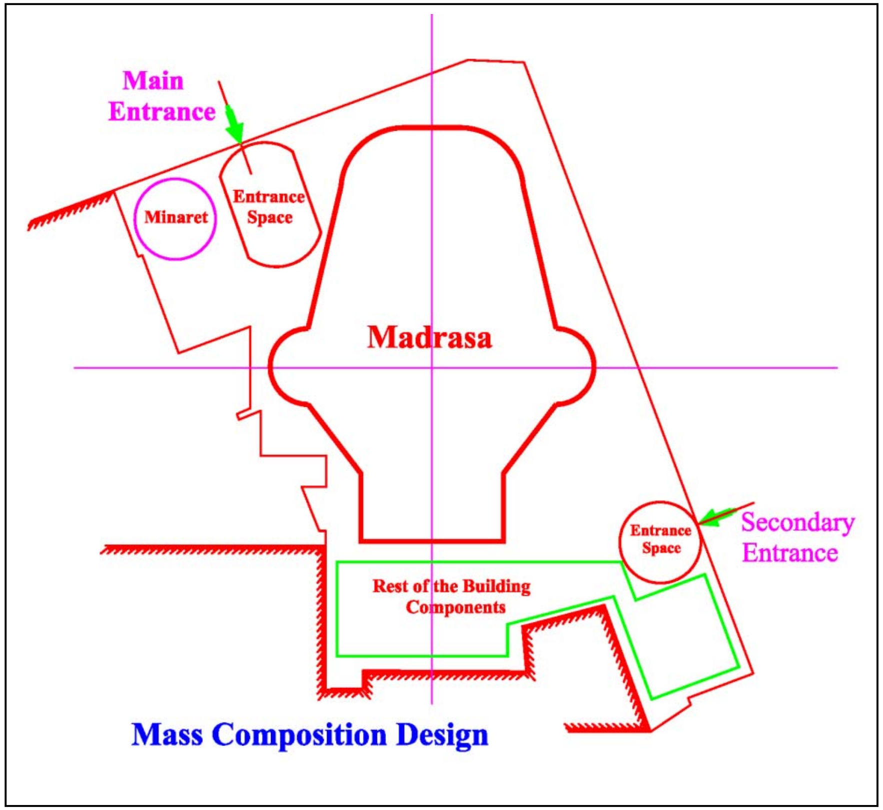
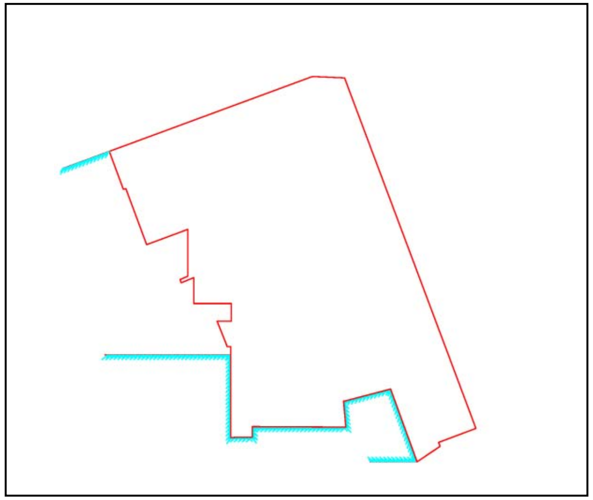
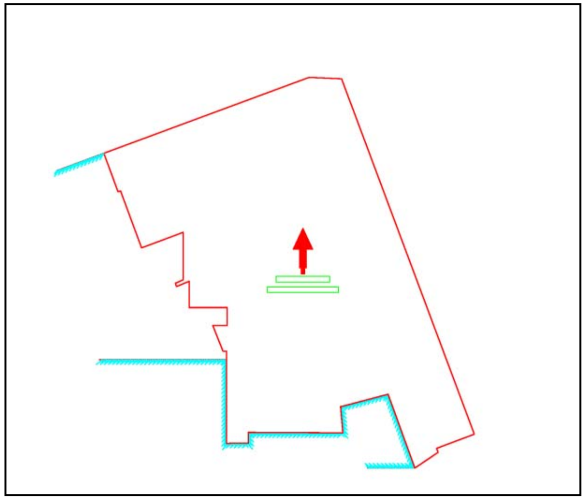


Figure 5-64: The mass composition in Madrasa of Qadi Abu Bakr Muzhir

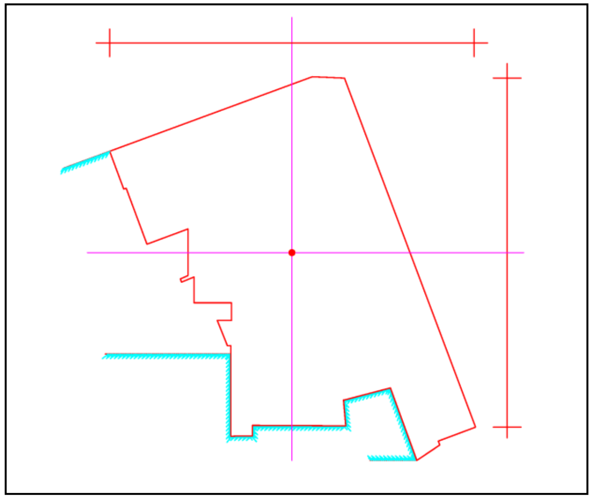
1- First Step: Determining the Site Boundary, the Qibla Direction and the Sahn’s Centre Point.



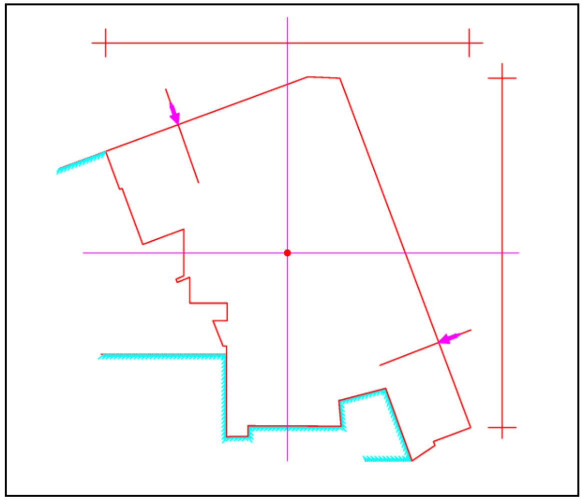
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

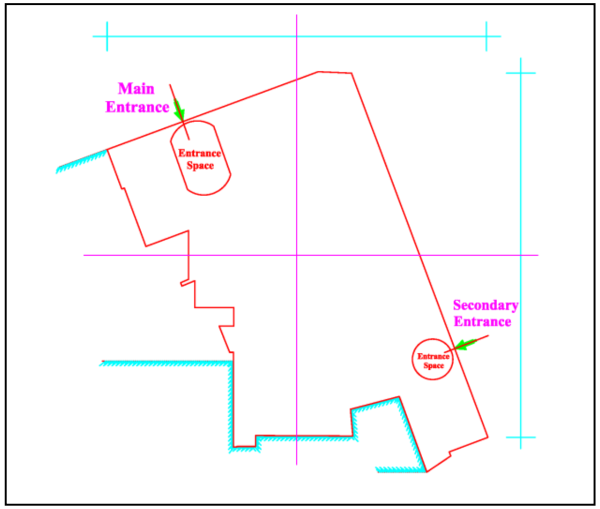


c- Determining the sahn’s centre point

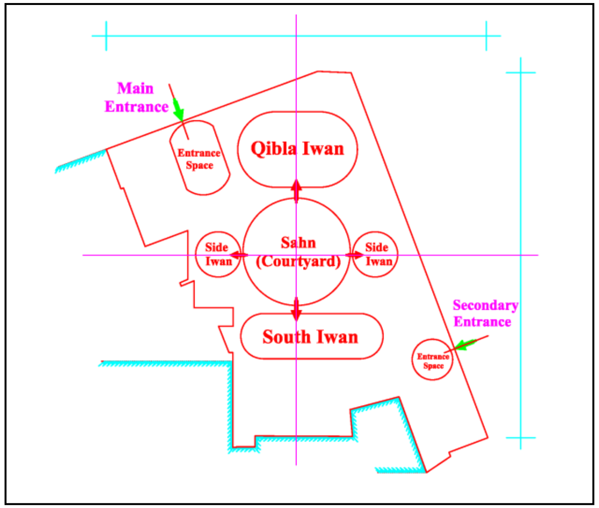


d- Adding the main entrance axis

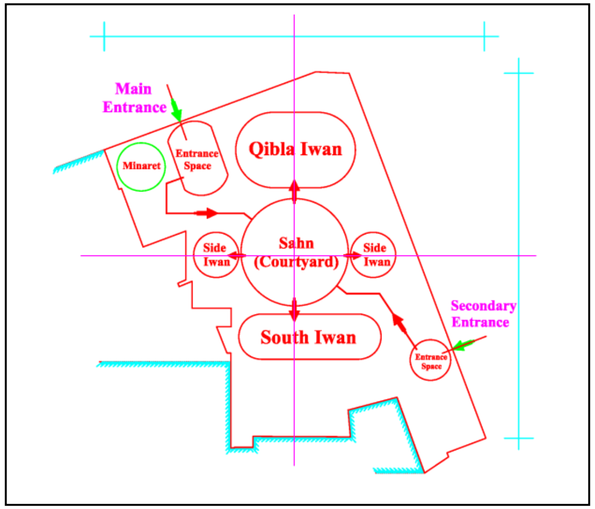
<u>2- Second Step:</u> Determining the Functions' Relationships and the Users' Circulations Diagram.



a- Determining the entrances position



b- Determining the sahn and all iwans position



c- Determining the minaret position

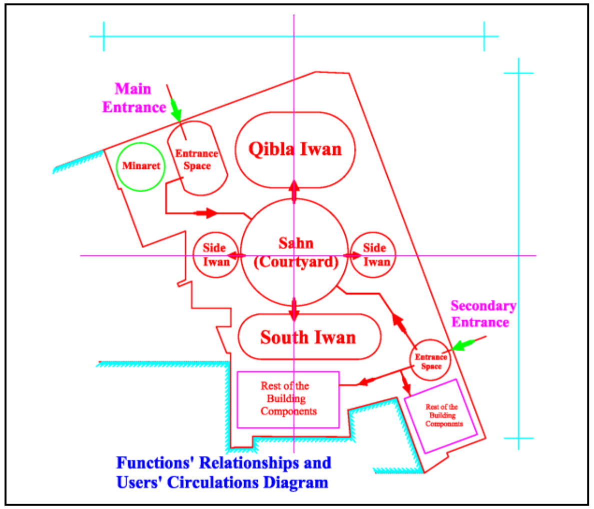
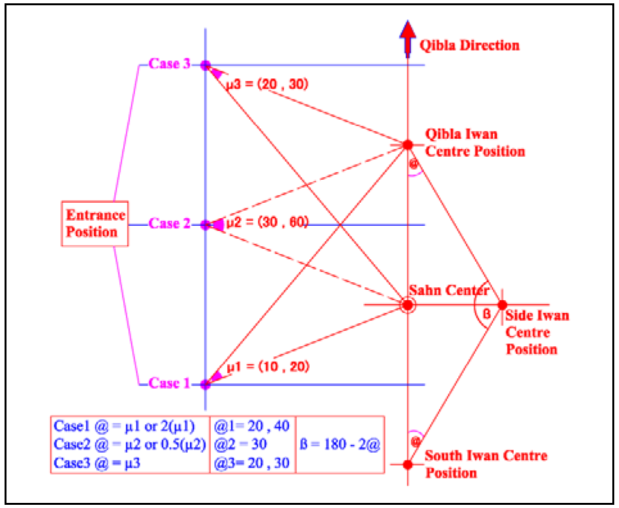
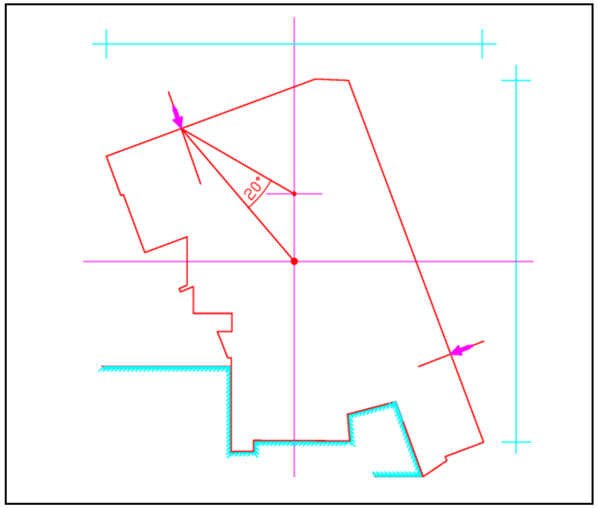


Figure 5-65: The final functions' relationships diagram in Madrasa of Qadi Abu Bakr Muzhir

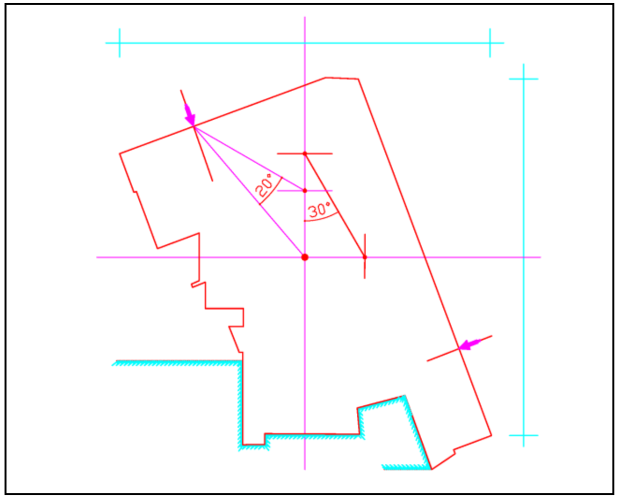
<u>3- Third Step:</u> Applying the Hidden Geometric System (Determining **µ**, **@** and **ß** angles).



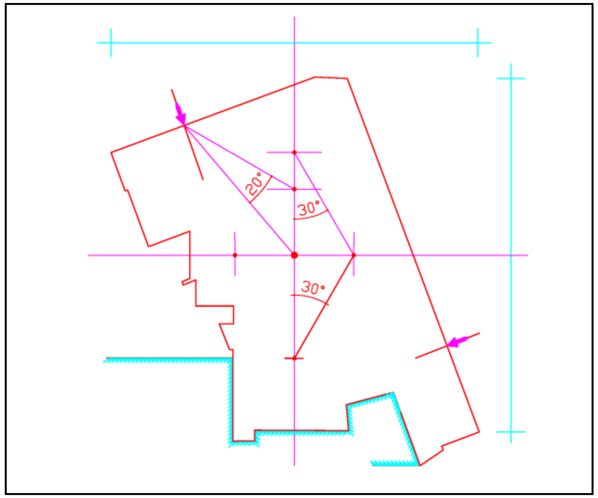
a- The hidden geometric system
(Determining the **µ**, **@** and **ß** angles)



b- Determining the qibla iwan's centre point.
(Applying the **µ** angle)



c- Determining the side iwan's centre points.
(Applying the @ angle)

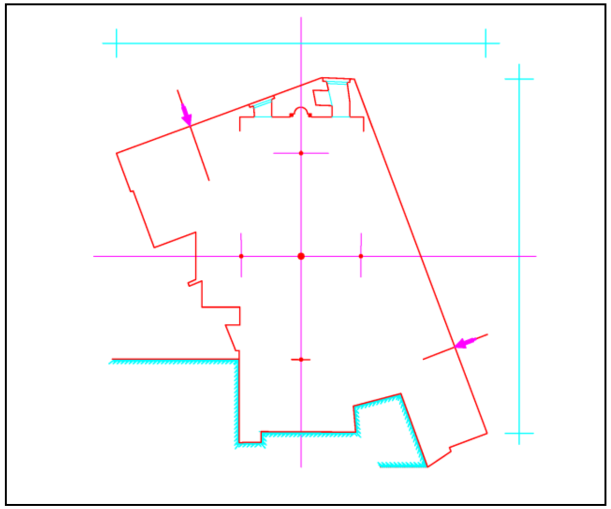


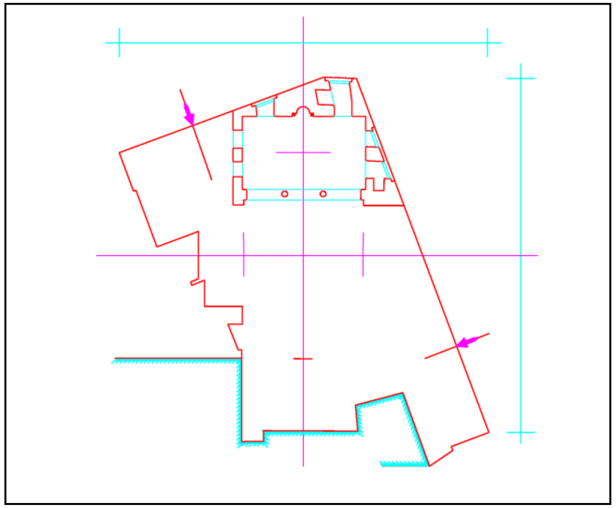
d- Determining the south iwan's centre point.
(Applying the ß angle)

<u>4- Fourth Step:</u> Generating the Building Plan's Design (the design of the building in 2D).

1- Generating the Qibla Iwan (Praying Hall)

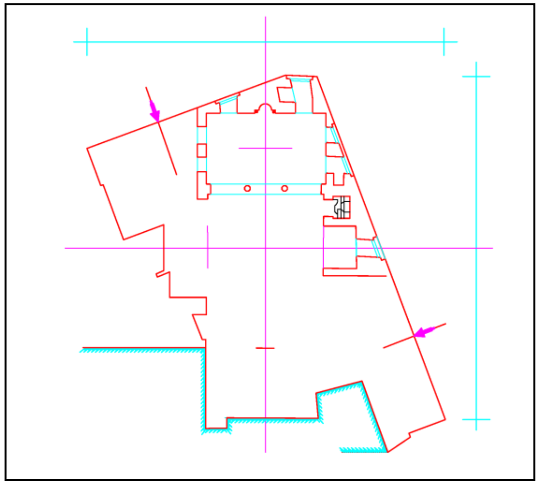
a- Designing the qibla wall



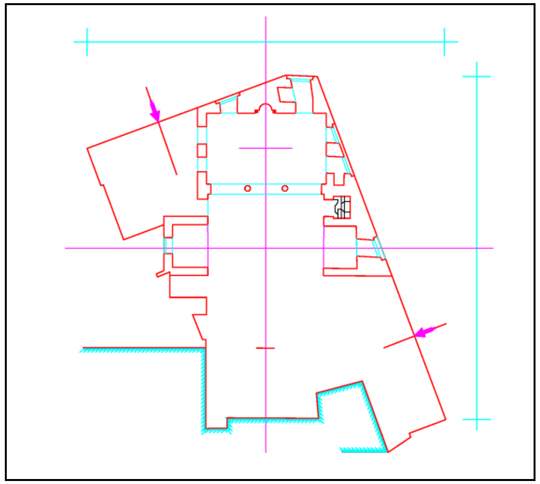


b- Completing the design of the qibla iwan.

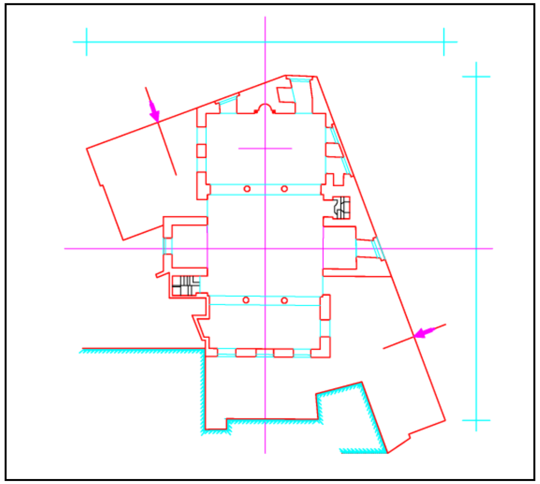
2- Generating the Sahn (Courtyard) and the Three Rest Iwans



a- Designing one of the side iwans

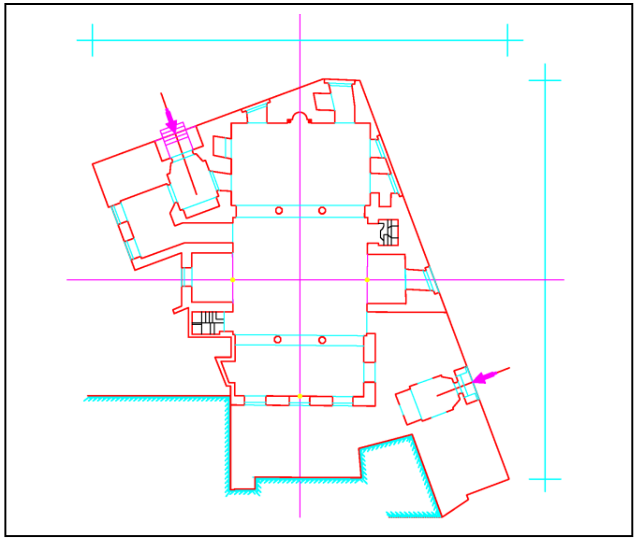


b- Designing second side iwan

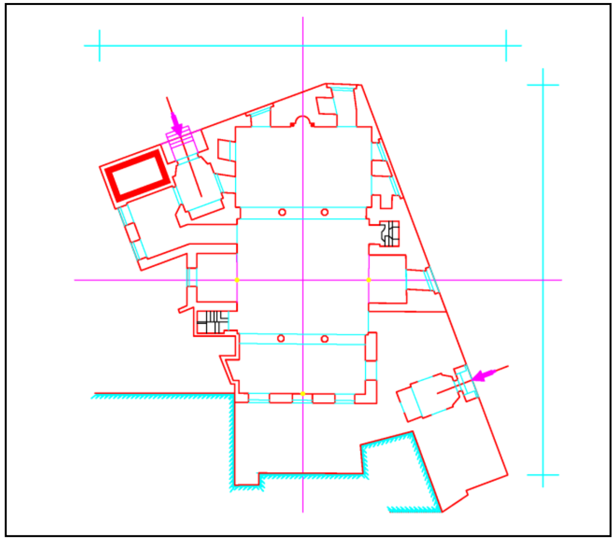


c- Completing the sahn and the south iwan design

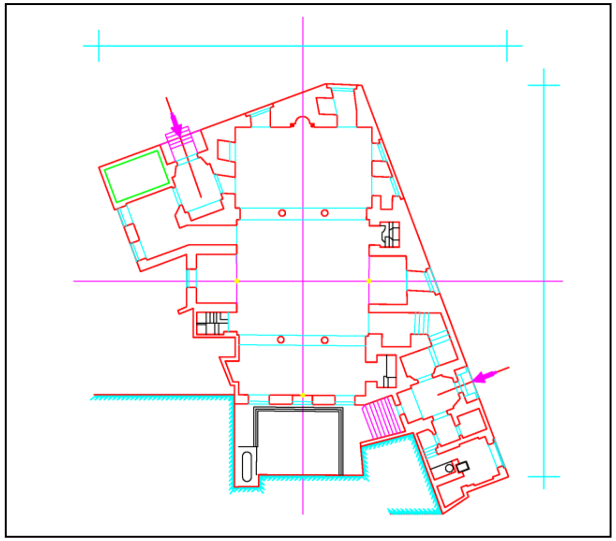
3- Adding the Entrance Design



4- Determining the Position of the Minaret



5- Completing the Rest of the Building's Spaces



6- The Final Building Plan with the H.G.D. system

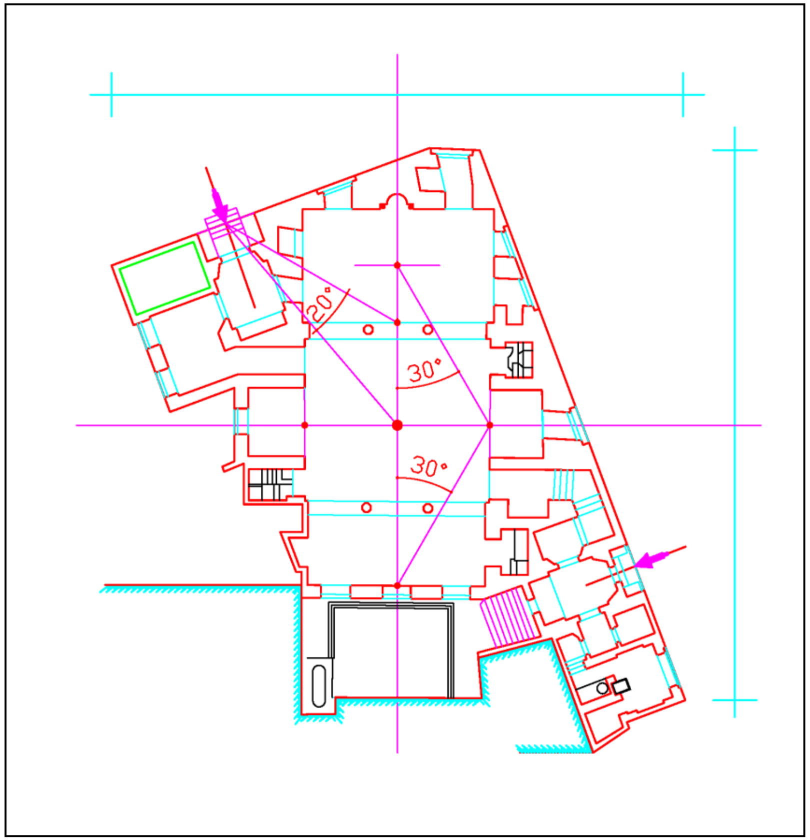


Figure 5-66: The final plan with the hidden geometric design system in Madrasa of Qadi Abu Bakr Muzhir

7- Generating the Final Building Plan

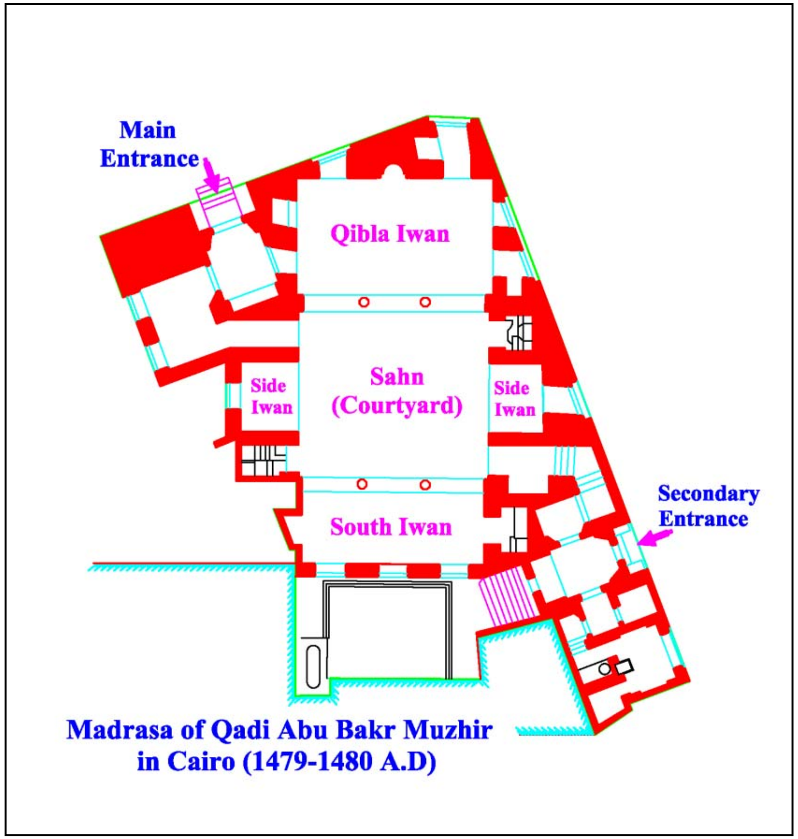


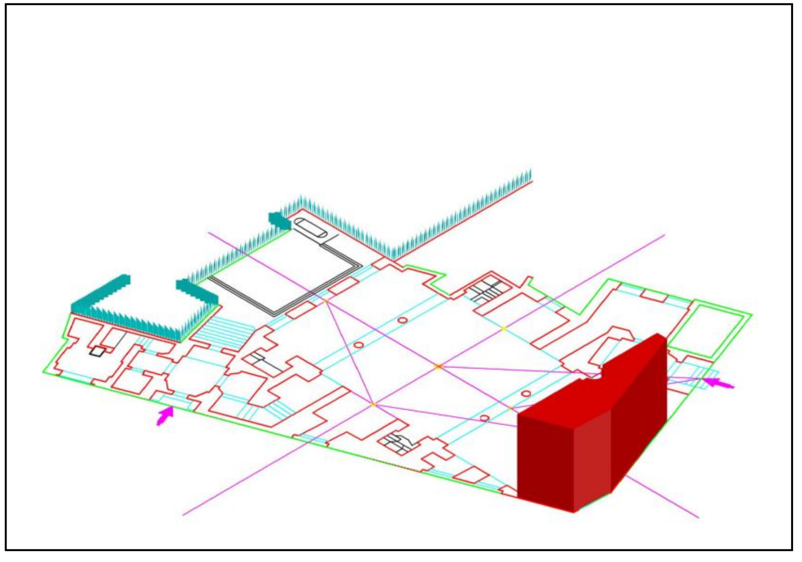
Figure 5-67: The final plan in Madrasa of Qadi Abu Bakr Muzhir

<u>5- Fifth Step :-</u> Applying the Interior Space Design Rules.
These are the results of applying the interior space design rules in Madrasa of Um al-Sultan Sha'ban:
* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.
* The entrance spaces are roofed and their height is equal to the building's total height.
* The design follows the roofed courtyard type.

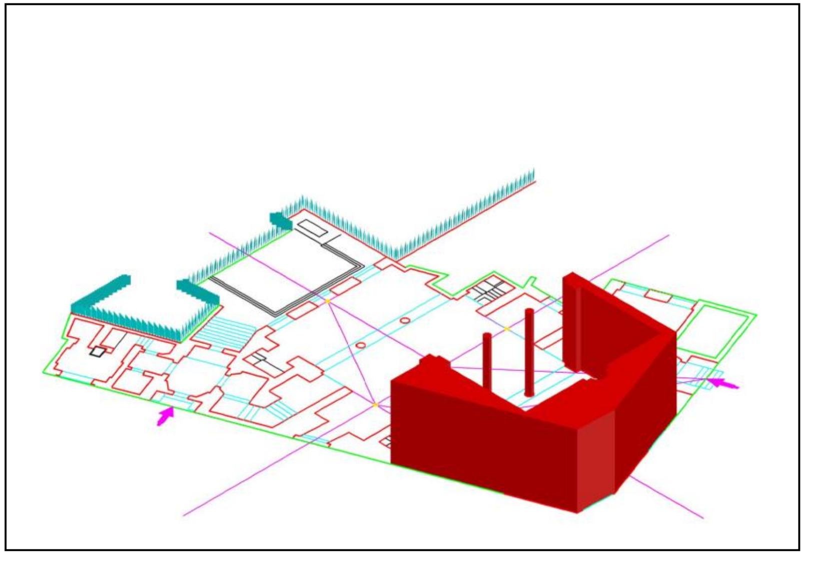
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans, which he has designed, into three-dimensional spaces.

<u>6- Sixth Step:</u> Generating the Building Spaces' Disposition (the design of the building in 3D).

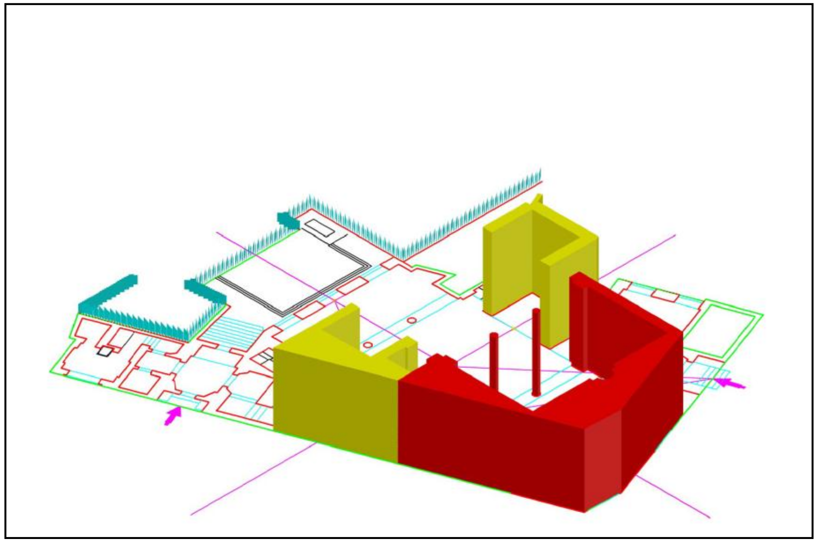
1- Constructing the Qibla Wall



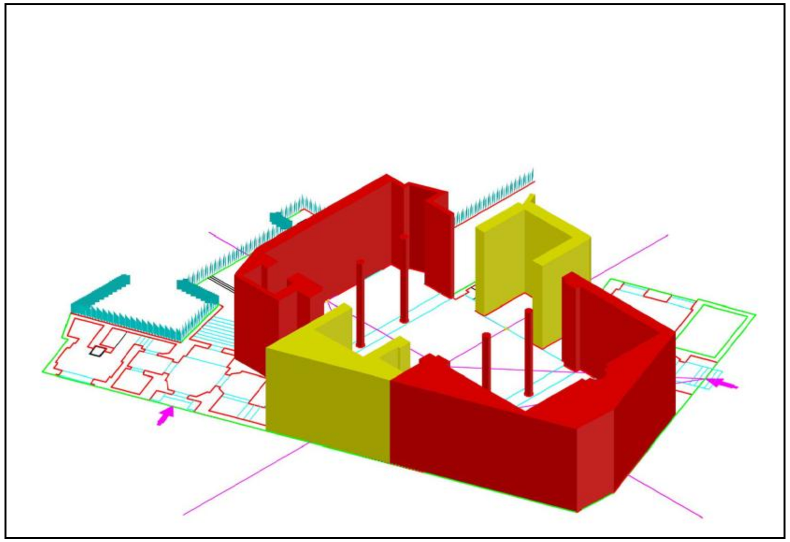
2- Completing the Qibla Iwan



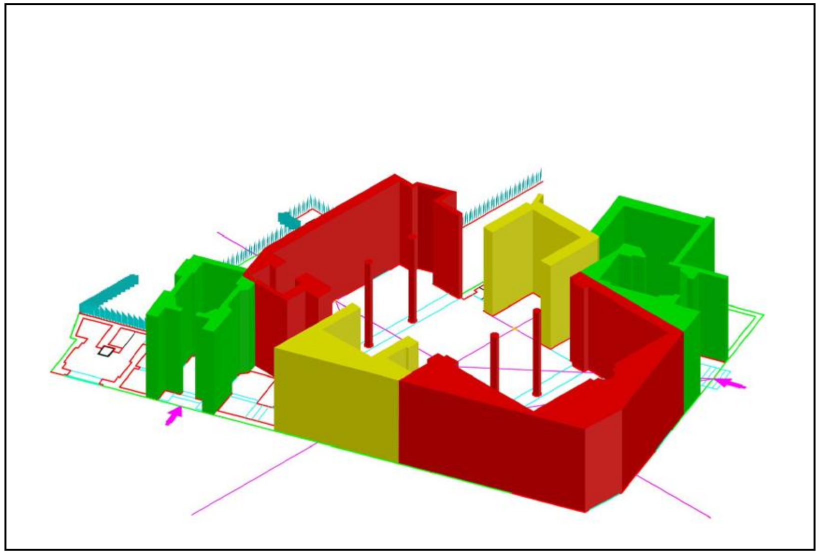
3- Constructing the Side Iwans



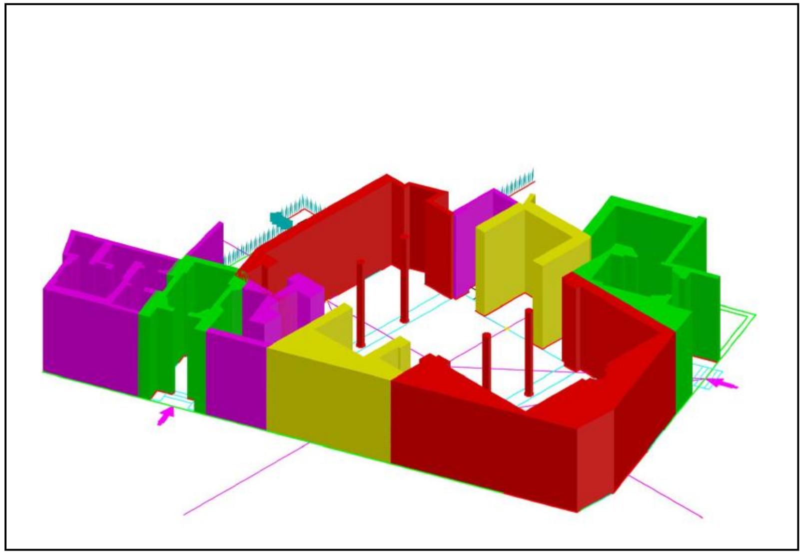
4- Constructing the South Iwan



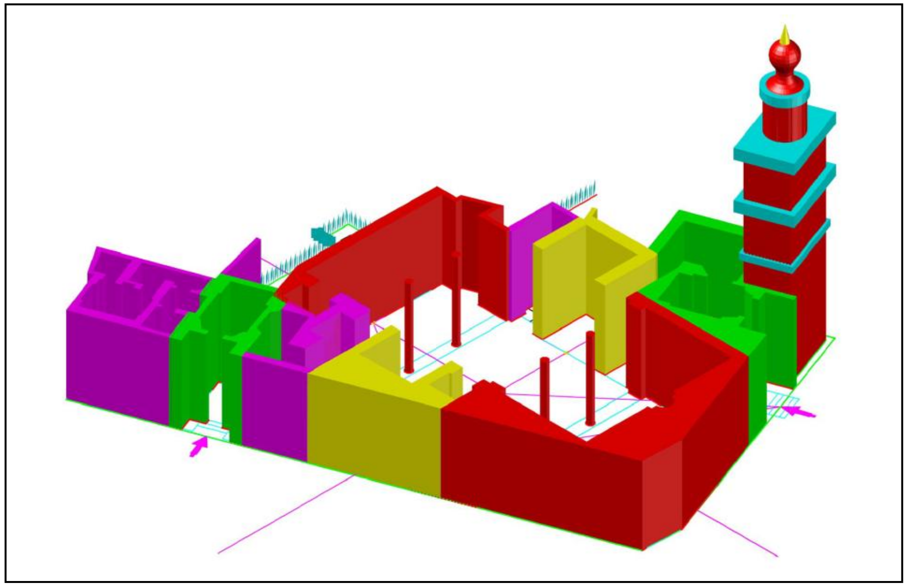
5- Constructing the Entrance and its Spaces



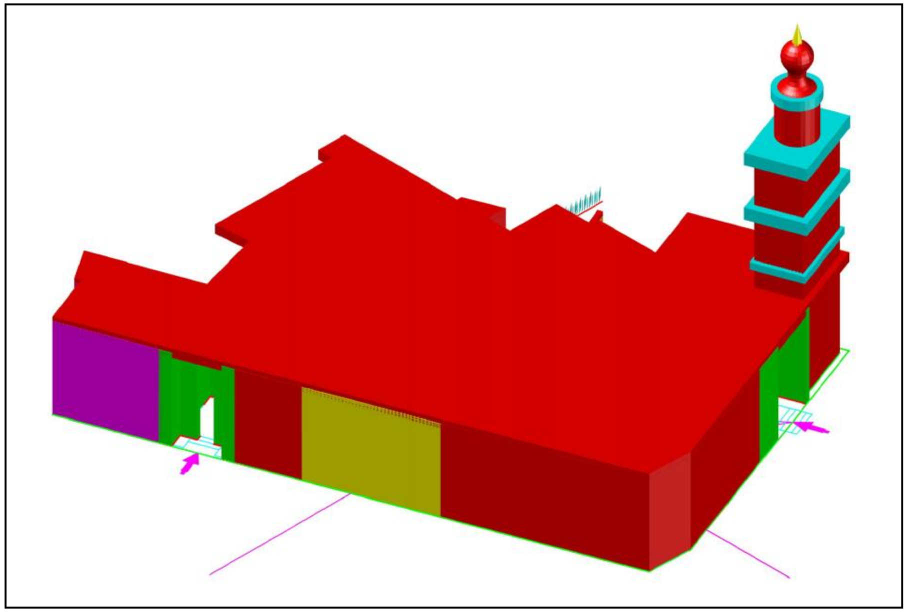
6- Constructing the Rest of Building's Spaces



7- Constructing the Minaret



8- Roofing the Building



5.2.1.7 Madrasa of Sultan Qansuah al-Ghuri (1502-4 A.D.)

1- General Description:

The funerary complex of Sultan al-Ghuri in al-Mu'izz Street is interesting as an architectural composition, built on both sides of a street. The western side includes a Friday madrasa-mosque, built on the four-iwan composition plan and the eastern side includes a khanqah and mausoleum, as well as Sabil-Kuttab.

Variant Names	* Madrasa of Sultan Qansuah al-Ghuri * Funerary Complex of Sultan Qansuh al-Ghuri. * Khanqah-Mausoleum-Sabil-kuttab of Sultan Qansuh al-Ghuri. * Mosque-Madrasa of Sultan Qansuh al-Ghuri (Khanqah, Mausoleum, Sabil-Kuttab, Mosque and Madrasa). * Complex of al-Ghouri. * Complex of al Ghuri. * al-Ghuriya. * al-Ghuriyya. * al-Ghouriyya.
Street Address	Al-Mu'izz li-Din Allah Street
Location	Cairo, Egypt
Date	16^{th} (1503-1505 A.D.)
Style/Period	Mamluk (Circassian)
Building Types	Complex (Educational, Funerary, Religious)
Building Usage	Madrasa, Mausoleum, Mosque. Sabil-Kuttab

Table 5-7: The general description of Madrasa of Sultan al-Ghuri

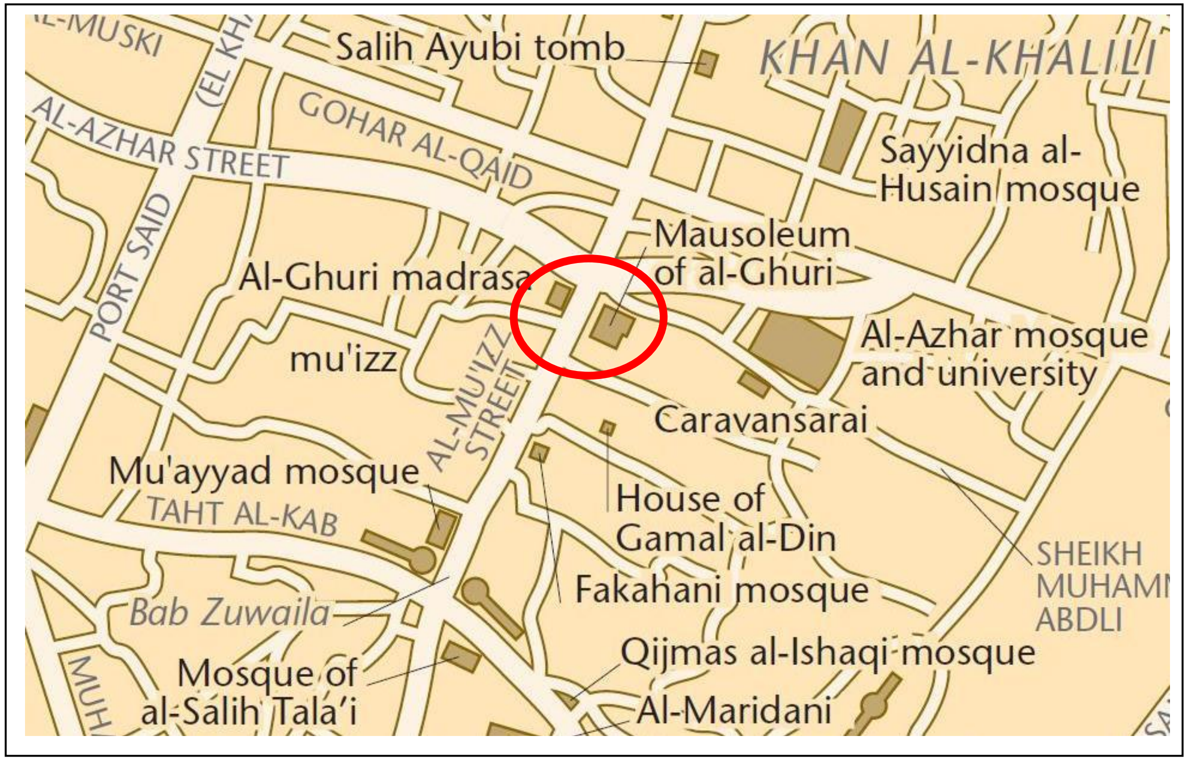


Figure 5-68: The site of Madrasa of Sultan al-Ghuri

Figure 5-69: The in-between space in Madrasa of Sultan al-Ghuri

2- Building an architecture description

a- The Layout

The complex masses straddles both sides of al-Mu'izz Street, with the congregational mosque-madrasa built on the western side and the khanqah-mausoleum-sabil-kuttab on the eastern side. The plan of both spaces is shifted to accommodate the qibla orientation, as shown in Fig. (5-69).

b- The Plan

The mosque was built according to the four iwan madrasa plan. It consists of a sahn, surrounded by four iwans; the qibla iwan and the one opposite to it being larger than the side ones.

c- The Facades

The mosque has three facades: the most important being the eastern one overlooking the Shari' al-Mu'izz Li-Din Allah, the lower part of which is occupied by shops. This facade comprises the main entrance and three rows of windows, all of which are above the level of the shops. Further above, runs a band of Mamluk inscriptions containing a Quranic verse, the name and titles of al- Ghuri, and some prayers in his favour. The facade is crowned by foliated cresting with a carved ornament on its outer face, see Fig. (5-70).

The facades of the complex flanking al- Mu'izz Street, unlike the earlier religious complexes in the city, are not adjusted to the street alignment. Instead they follow the orientation of the two sides of the complex. Since the two opposing facades are both set back from the original lines of the street, this divergent portion of the street is transformed into some sort of a square which is semi-enclosed at the north end by the projection of the Sabil-kuttab of the mausoleum, and at the south end by the projection of the minaret of the madrasa. The thoroughfare is expanded so the patron could incorporate the urban space into the complex and rent it out for market stalls. The income generated from these stalls and from the shops built into the lower levels on the qasaba facades contributed to Sultan al-Ghuri’s endowment.

The main entrance is in Shari' al-Mu'izz Li-Din Illah. The entrance is decorated with black-and-white marble and covered by a stalactite hood. The two halves of its door are covered with pierced brass, and pierced with beautiful ornaments, as shown in Fig. (5-71).

The main entrance, reached after a few steps, leads into a square vestibule with a fine polychrome marble floor. Its timber ceiling is decorated and gilt embellished. From this vestibule one passes into a corridor leading into the sahn.

Figure 5-70: The main facade in Madrasa of Sultan al-Ghuri

d- The Minaret

The minaret is a four-storey, rectangular structure from the bottom to the top, with arched panels on each side. The top originally had four bulbs instead of just one, made of brick and covered with green tiles. The present five bulbs are a late reconstruction. This minaret and the original minaret of Aqsunqur are the only documented minarets with four stories instead of the standard three, see Fig. (5-72).

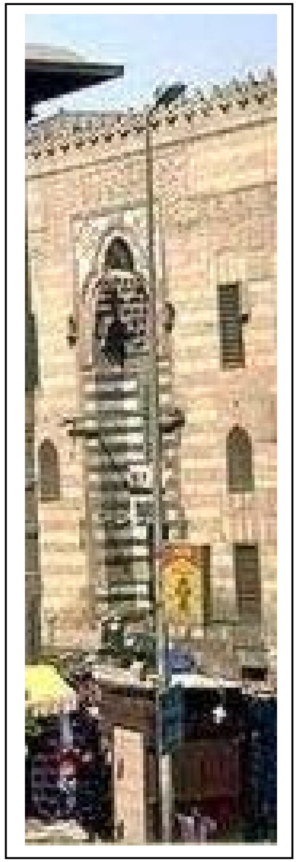


Figure 5-71:: The entrance in Madrasa of Sultan al-Ghuri

Figure 5-72: The minaret cmposition in Madrasa of Sultan al-Ghuri

e- The Mausoleum

This structure also has a trilobed stalactite portal. On its northern edge a sabil-kuttab is projected into the street with three facades. On the left or north side of the entrance visteibule there is a Qa'a that is called khanqah.

The mausoleum faces the madrasa. There is a stalactite portal next to its north corner, decorated with marble set into the stone, similar to the madrasa entrance. It also has two rows of windows in recesses; the lower ones have lintels with joggled voussoirs of black-and-white marble. The upper windows are in groups of three arches, two arched ones, the arches of which are supported by three marble columns, and a circular one on top, between the arches. The facade ends with a foliated cresting, the faces of which are ornamented with decoration carved in the stone. At the northern end of this facade there projects a sabil with three large windows with iron grilles, and a fine marble floor. Above the sabil is a kuttab, in each of the three sides of which there are two arches, supported by columns. It has a wooden awning supported by wooden brackets. The entrance is reached by a flight of steps; it leads into a square vestibule, with a decorated ceiling and a marble floor, similar to that of the mosque. On the right side of the vestibule there is a door leading into the mausoleum, of which only the walls and the zone of transition remain. These are rich with decoration and inscriptions, engraved in the stone, Fig. (5-73) and (5-74).

Figure 5-73: The mausoleum and the sabil-kuttab in Madrasa of Sultan al-Ghuri

Figure 5-74: The facade of the mausoleum in Madrasa of Sultan al-Ghuri

3- Applying the Geometric Generative Technique :-

The geometric generative technique steps will be applied on Madrasa of Sultan al-Ghuri.

<u>Pre-Design step:</u>

In this step the designer begins by studying the building's urban context and formulates the composition of the masses in the building form.

1- Studying the building site's urban context.

2- Drawing the dialogue between the building and its surroundings.

a- Studying the position of the entrance

The building facades are unadjusted to the street alignment. They make an angle instead, leaving the space between the two facades to widen into a sort of square. The square was rented out for market stalls and the main entrances are located on the middle axes of this square, as shown in Fig. (5-75).

b- Studying the position of the dome

The designer chooses the position of the building's dome to complete the dialogue with the building minaret which is in confrontation, as shown in Fig. (5-76).

c- Studying the position of the minaret

The designer chooses the position of the building's minaret so that it is plays the role of landmark for the site, and pedestrians can see it from a distance, as shown in Figs. (5-77) and (5-78).

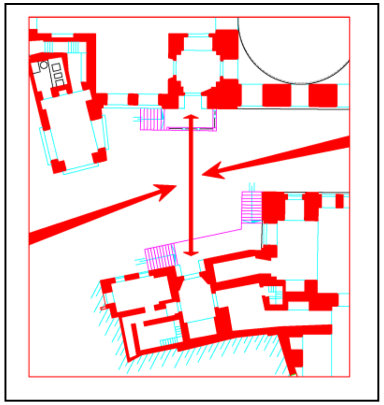


Figure 5-75: The position of the entrance in Madrasa of Sultan al-Ghuri

Figure 5-76: The position of the dome in Madrasa of Sultan al-Ghuri

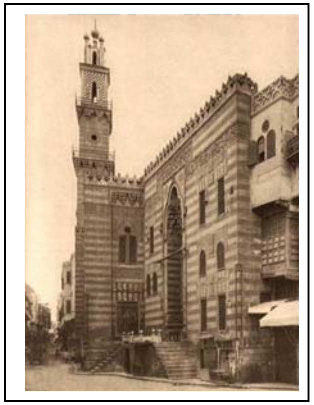


Figure 5-77: The position of the minaret in Madrasa of Sultan al-Ghuri

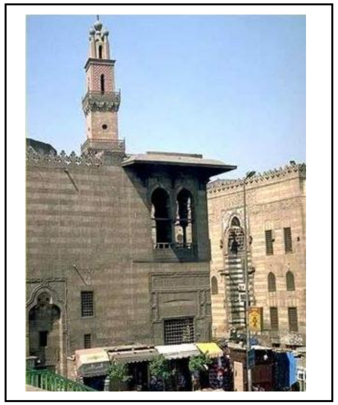


Figure 5-78: The minaret view from the side of the street in Madrasa of Sultan al-Ghuri

3- Suggesting the building mass composition.

From the building site urban analysis, the designer can determine the mass composition of the building, as well as the primary position of the madrasa, the mausoleum, the minaret and the entrance, as shown in Fig. (5-79).

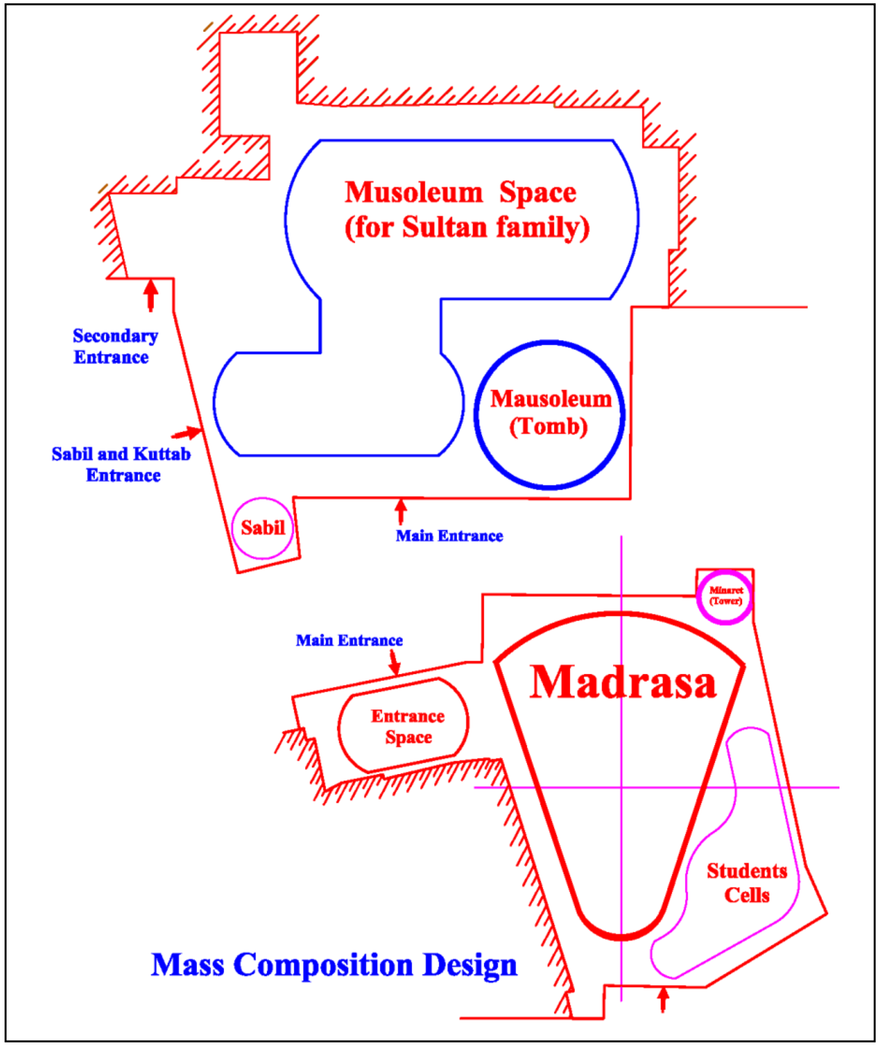
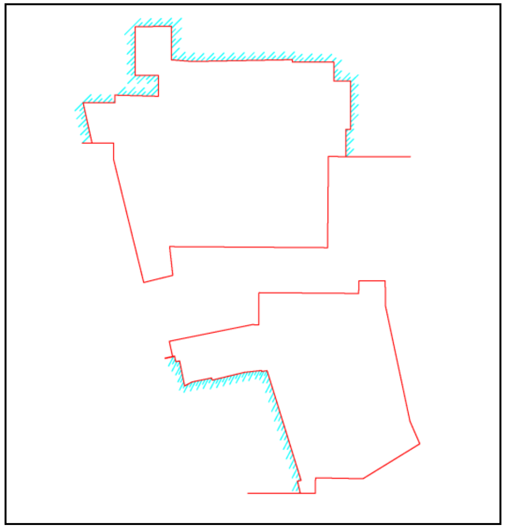
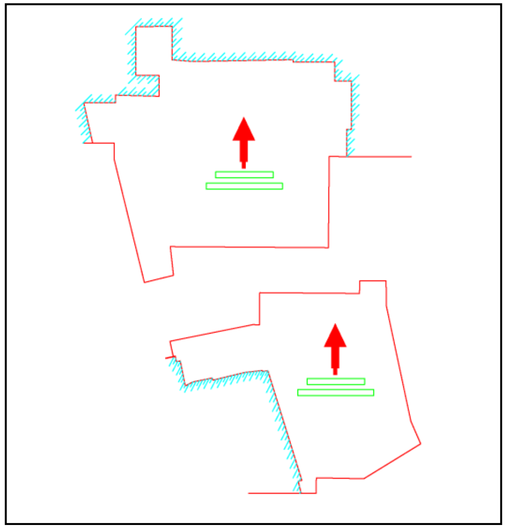


Figure 5-79: The mass composition design in Madrasa of Sultan al-Ghuri

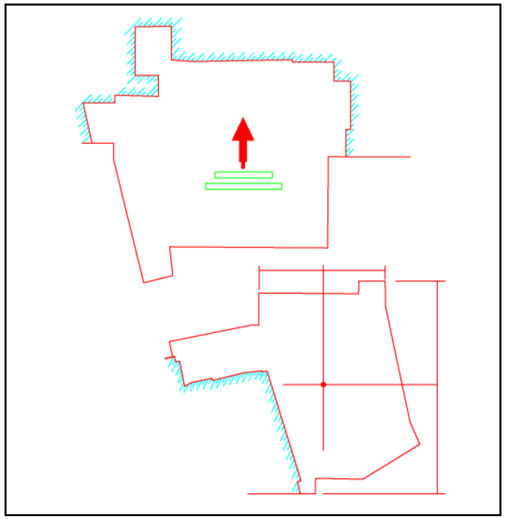
1- First Step: Determining the Site Boundary, the Qibla Direction and the Sahn's Centre Point.



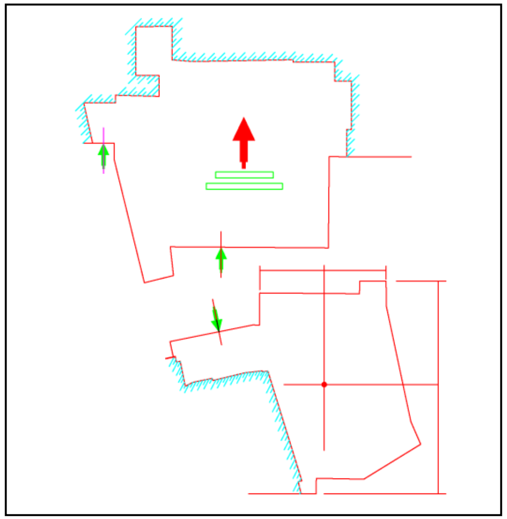
a- Determining the building site boundary



b- Determining the qibla direction (Makkah direction)

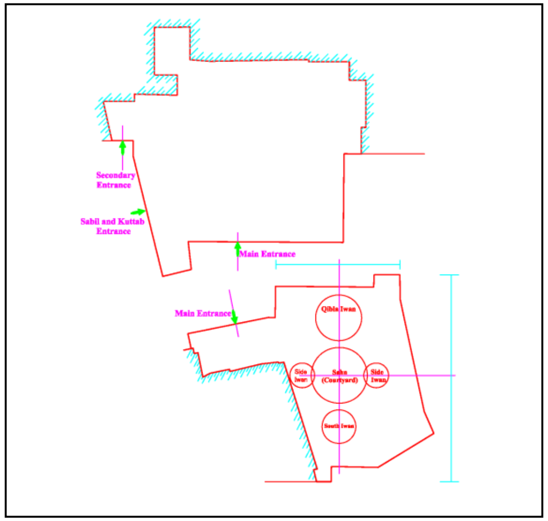


c- Determining the sahn's centre point

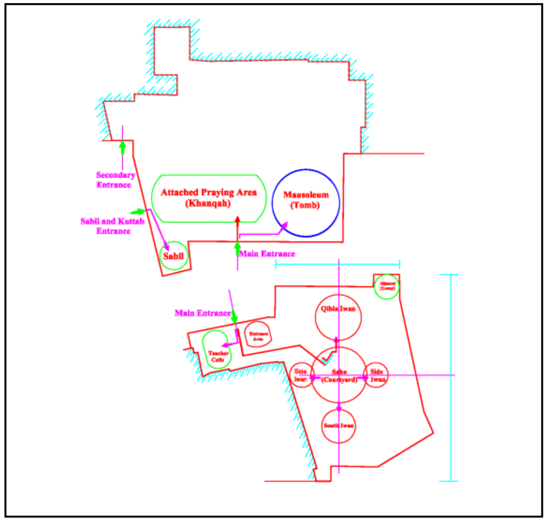


d- Adding the entrances axes

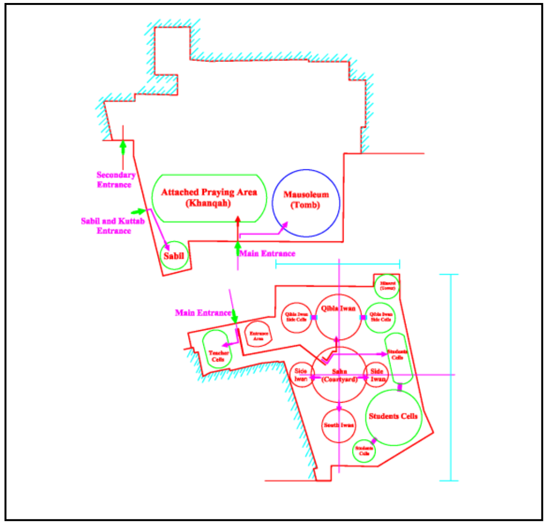
2- Second Step: Determining the Functions' Relationships and the Users' Circulations Diagram.



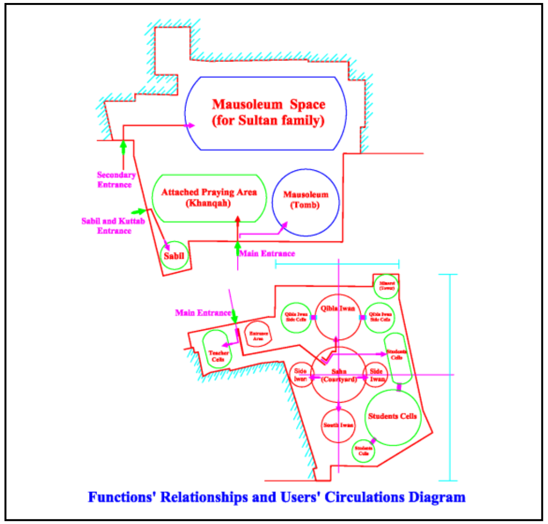
a- Determining the position of the sahn and all iwans



b- Determining the position of the mausoleum, minaret and sabil

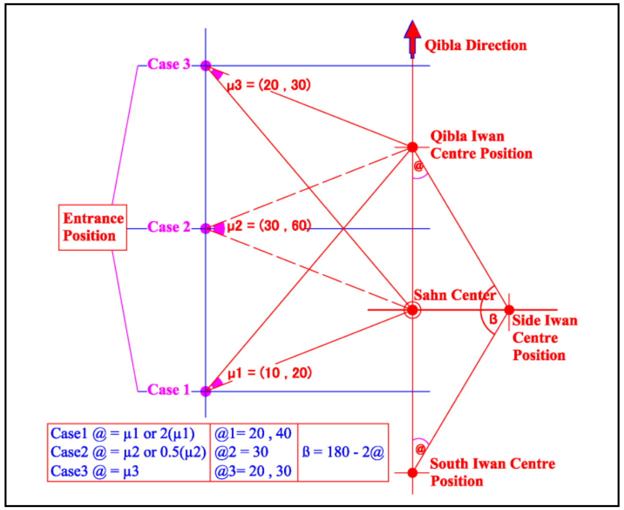


c- Determining the users' circulations between spaces

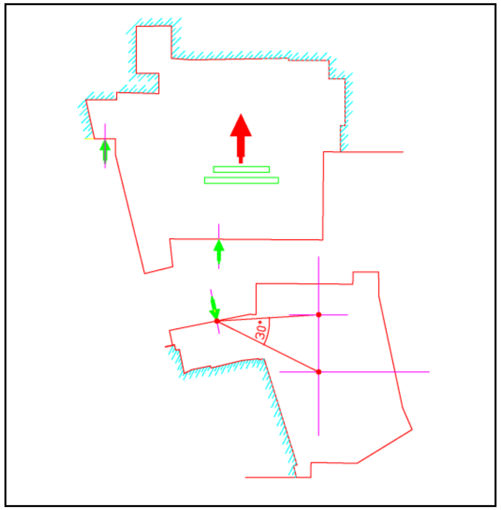


d- Determining the final functions' relationships diagram

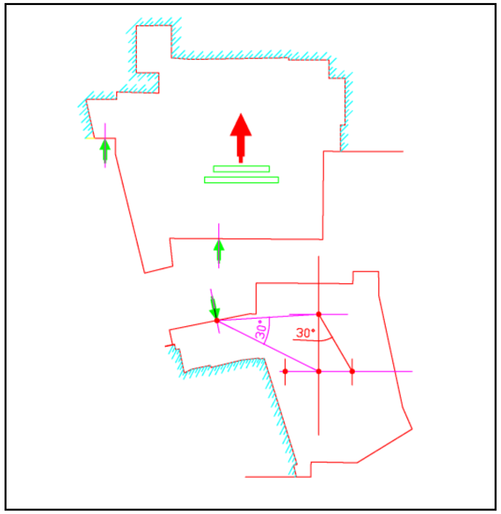
3- Third Step: Applying the Hidden Geometric System (Determining µ, @ and ß angles).



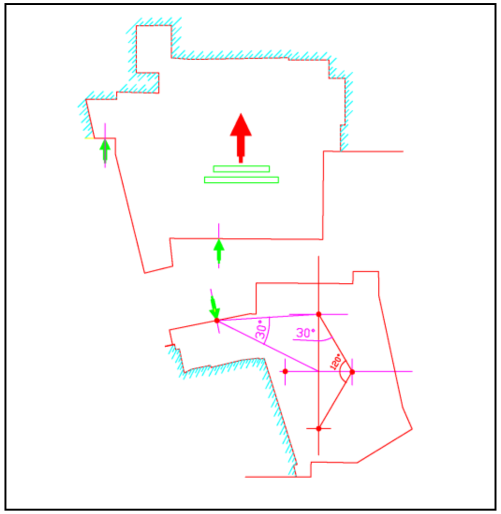
a- The hidden geometric system
(Determining the µ, @ and ß angles)



b- Determining the qibla iwan's centre point
(Applying the µ angle)



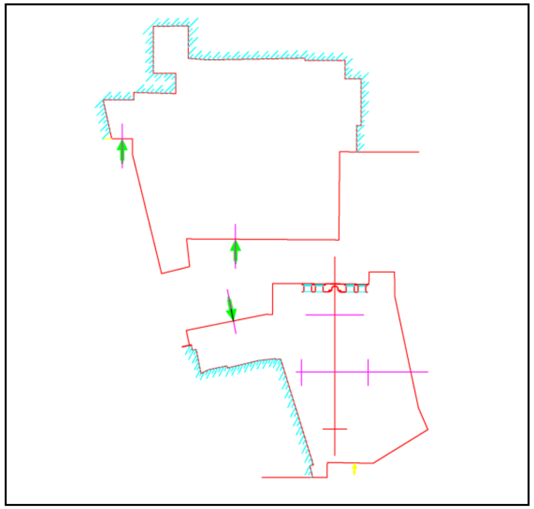
d- Determining the side iwan's centre points
(Applying the @ angle)



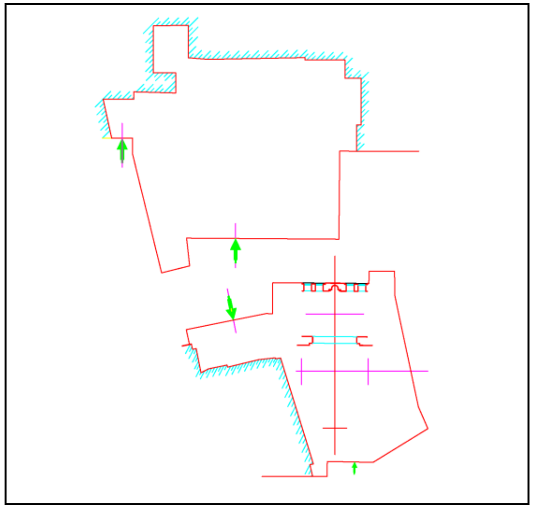
c- Determining the south iwan's centre point
(Applying the ß angle)

<u>4- Fourth Step :</u>- Generating the Building Plan's Design (The Design of the building in 2D).

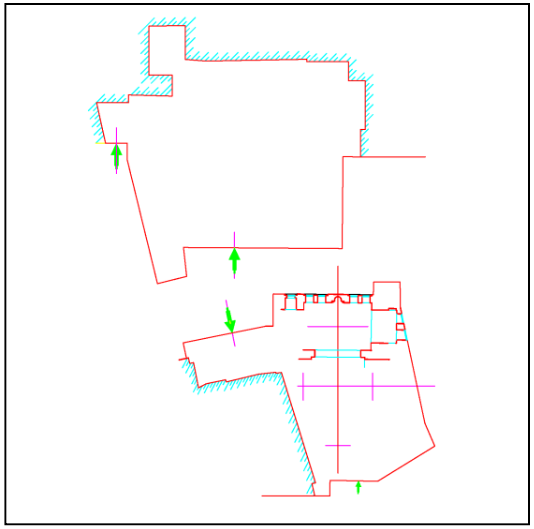
1- Generating the Qibla Iwan (Praying Hall)



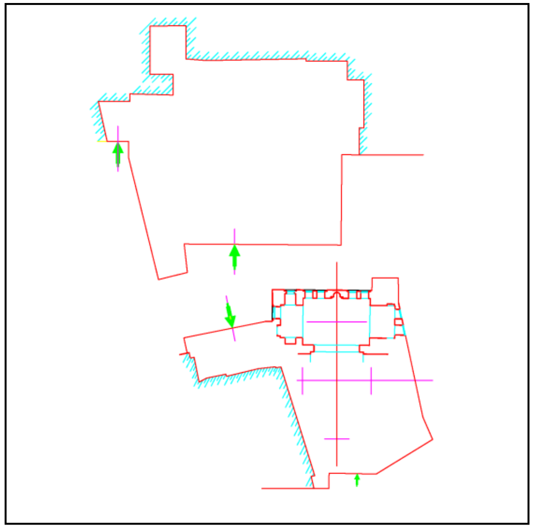
a- Designing the qibla wall



b- Designing the qibla iwan entrance wall from the sahn

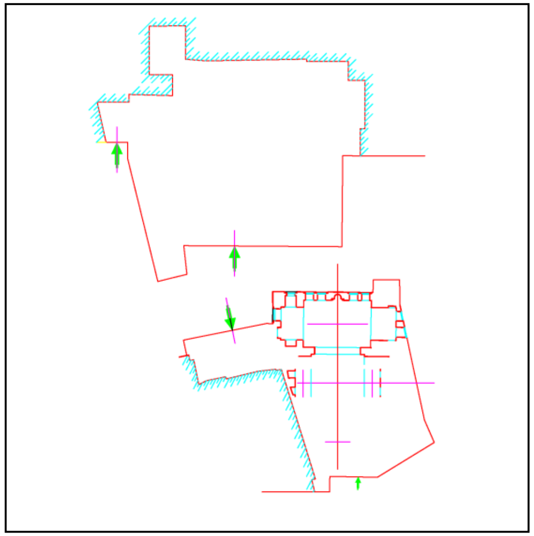


c- Designing the side cell of the qibla iwan

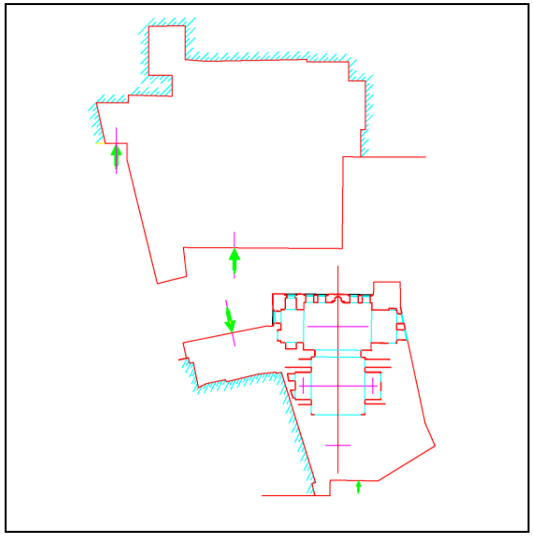


d- Completing the design of the qibla iwan

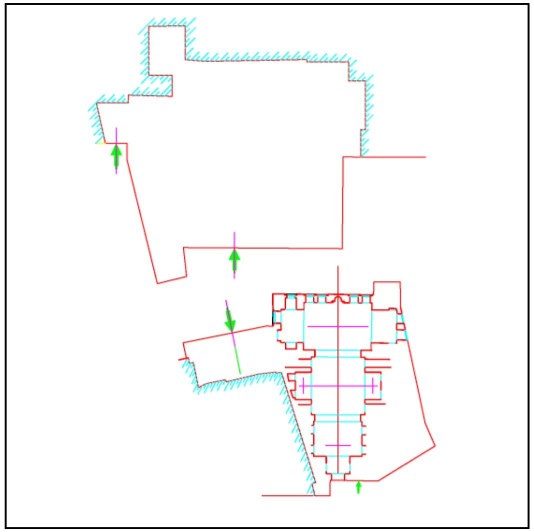
2- Generating the Sahn (Courtyard) and the Iwans



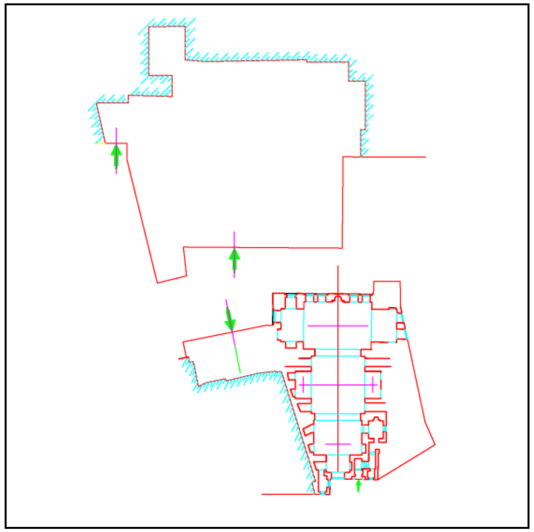
a- Designing one of the side iwans



b- Designing the second side iwans

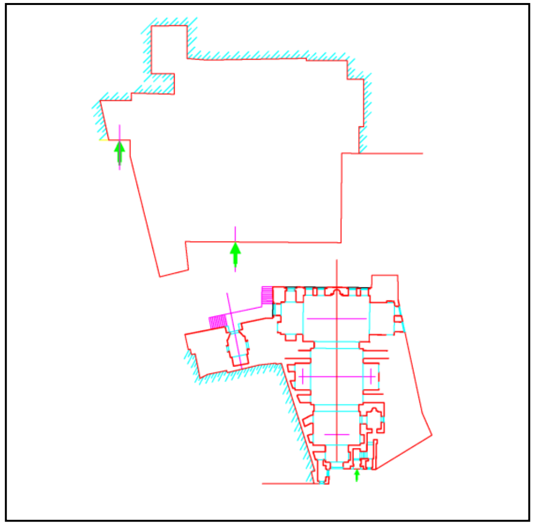


c- Completing the sahn and the south iwan design

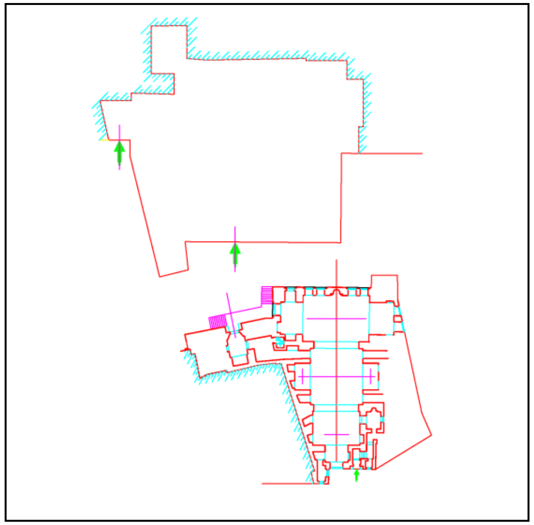


d- Completing the cells around the south iwan

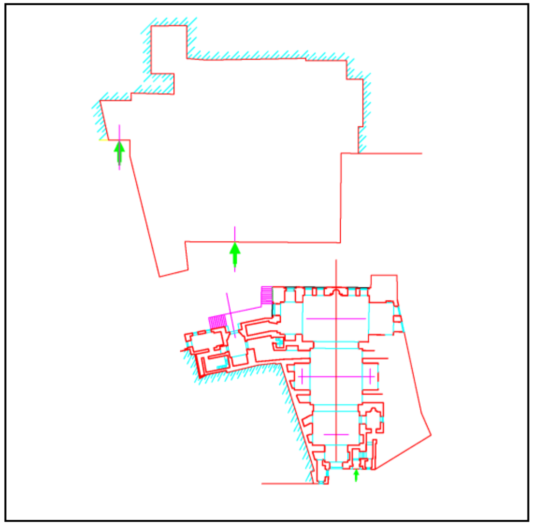
3- Designing the Entrance



a- Adding the entrance space form

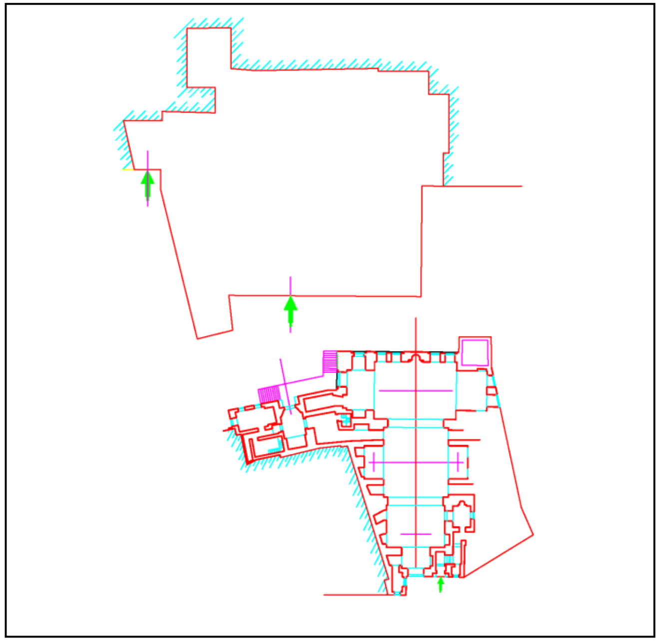


b- Designing the path from the entrance to the sahn

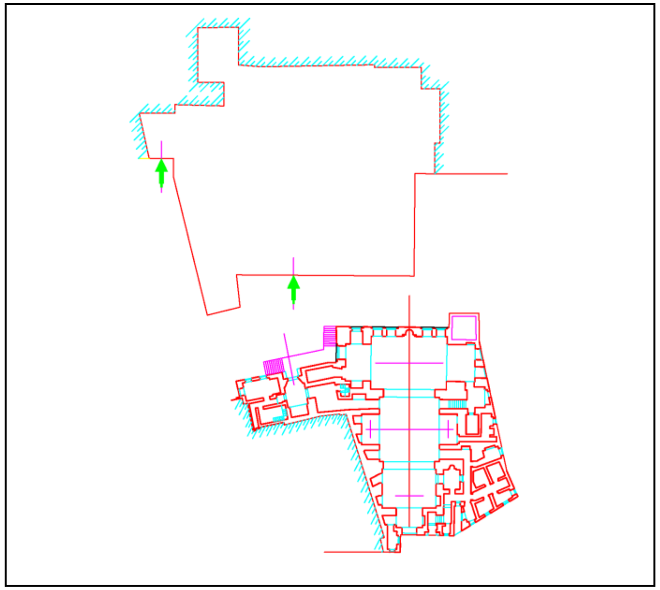


c- Completing the entrance cells

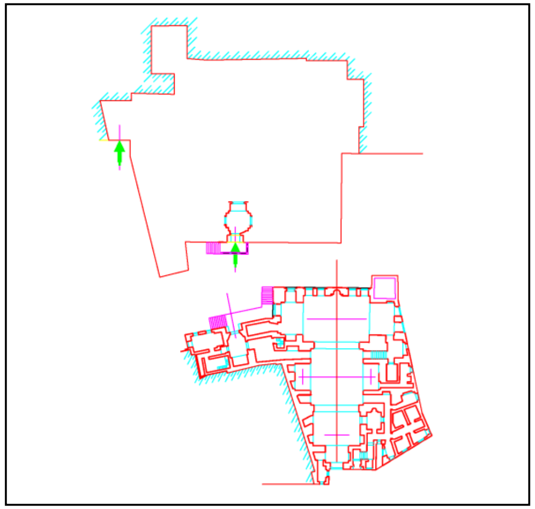
4- Determining the Position of the Minaret



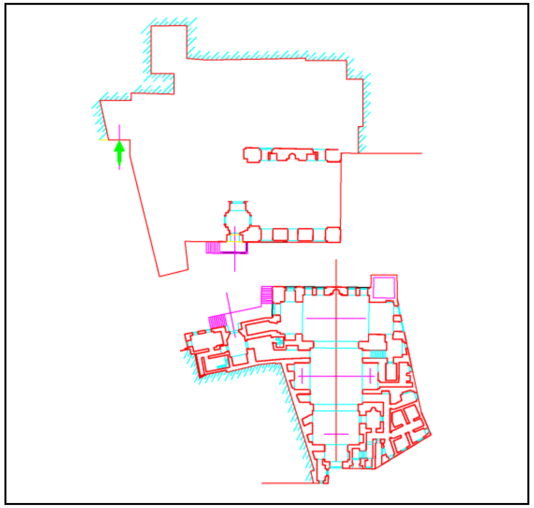
5- Designing the Student's Cells



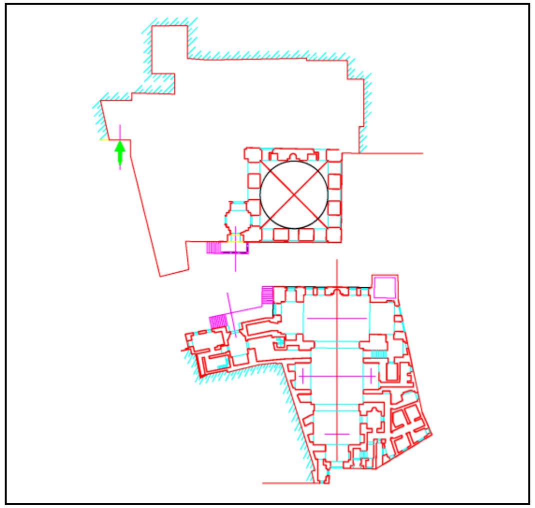
6- Designing the Mausoleum



a- Locating the form of the mausoleum entrance space

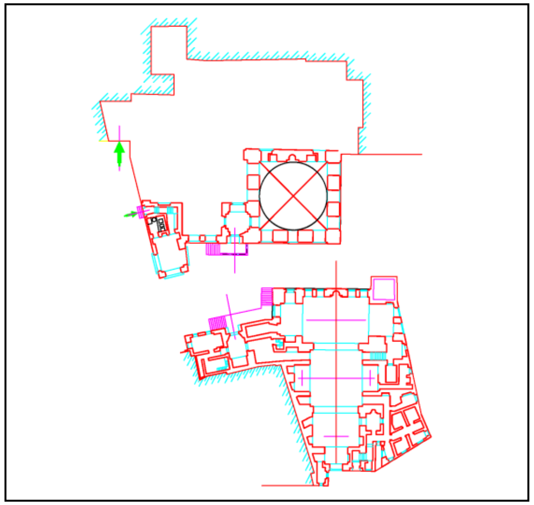


b- Designing the qibla wall inside the mausoleum

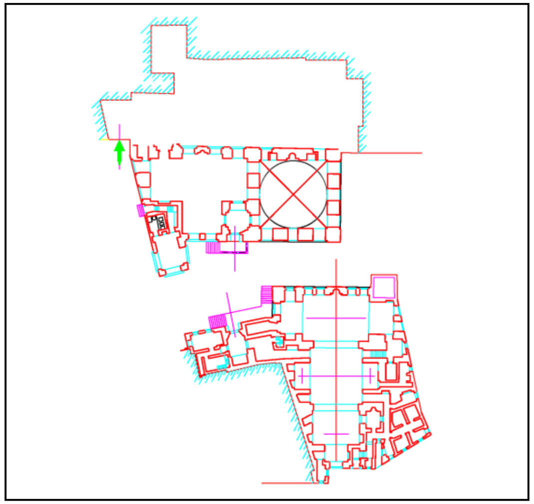


c- Completing the main space of the mausoleum

7- Designing the Sabil

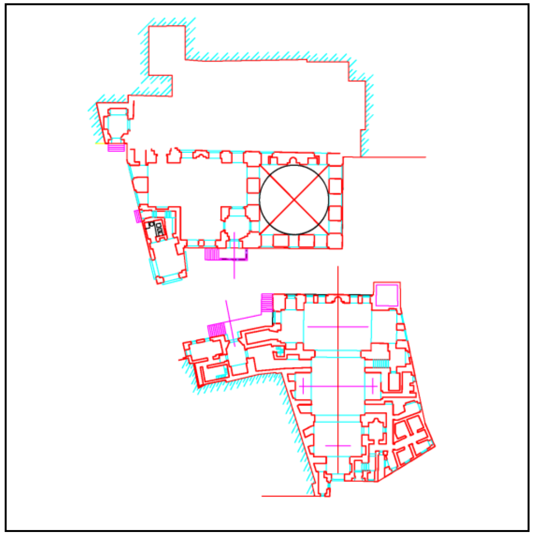


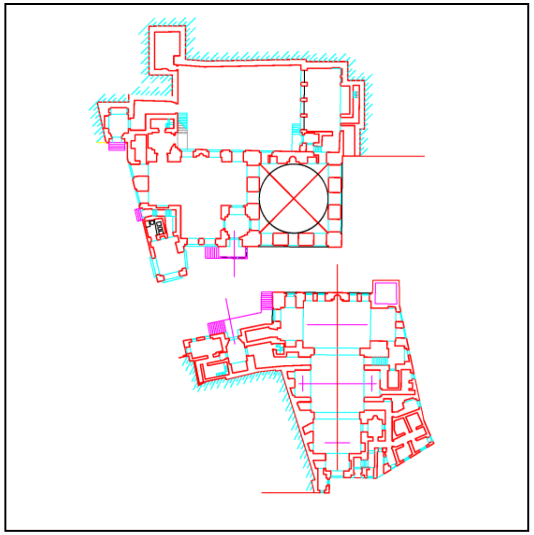
8- Completing the Khanqah



9- Designing the Attached Mausoleum Space

a- Adding the entrance to the attached mausoleum space





b- The final design of the mausoleum

10- The Final Building plan with H.G.D System

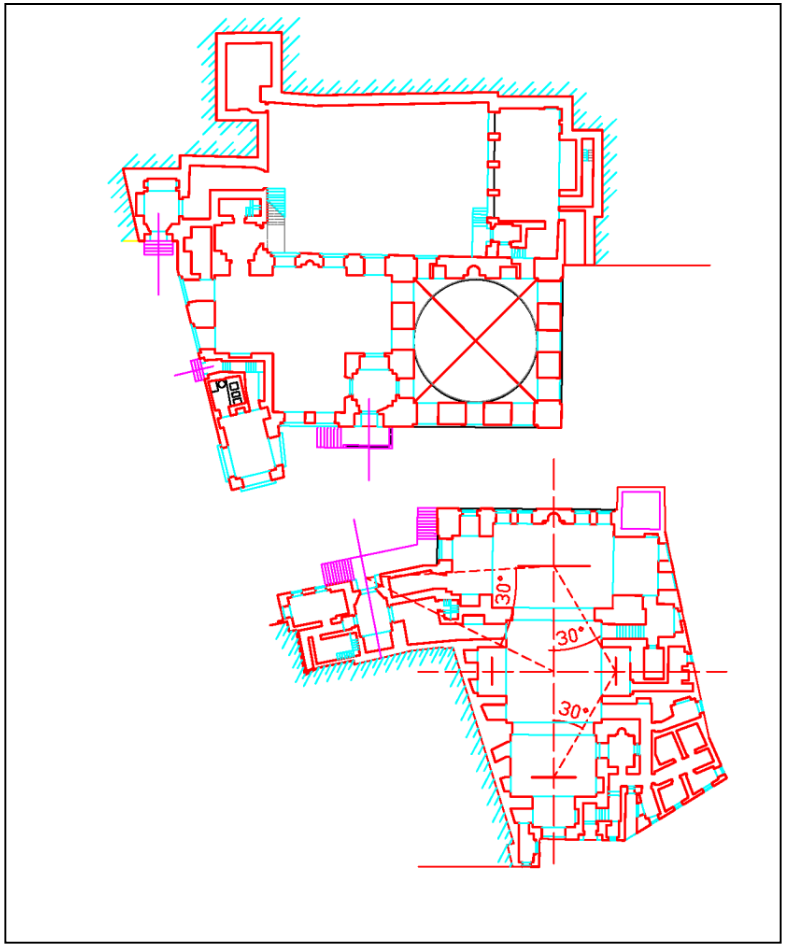


Figure 5-80: The final plan with the hidden geometric design system in Madrasa of Sultan al-Ghuri

11- The Final Building Design

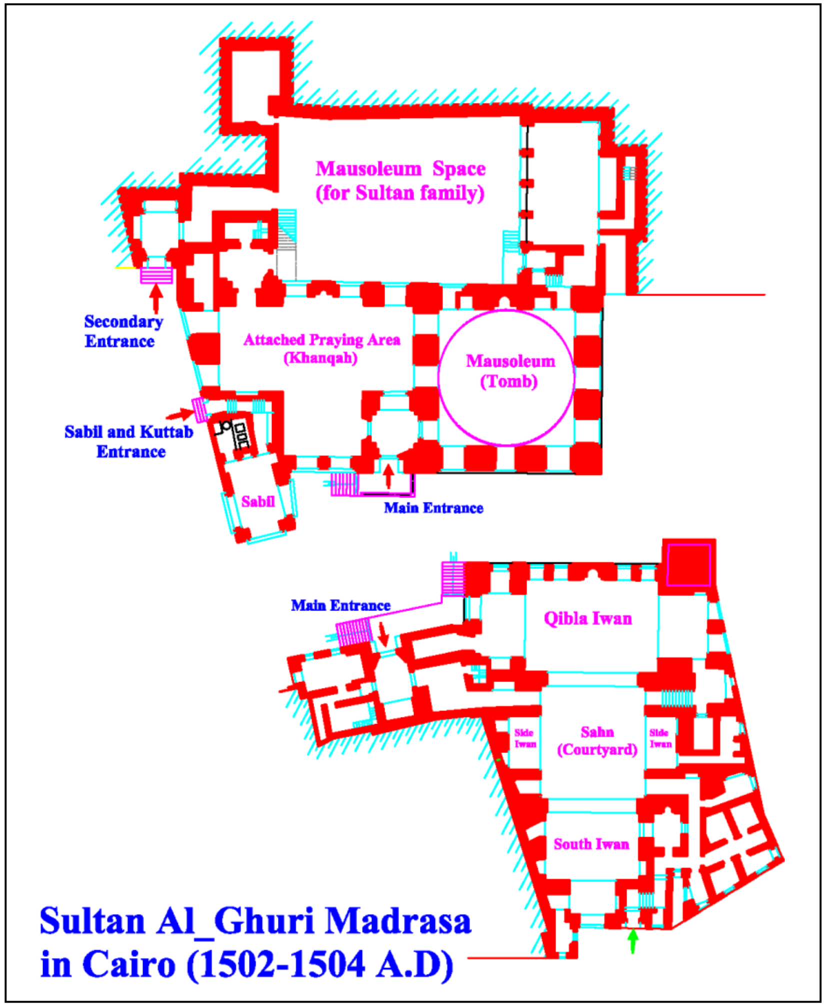


Figure 5-81: The final plan of Madrasa of Sultan al-Ghuri

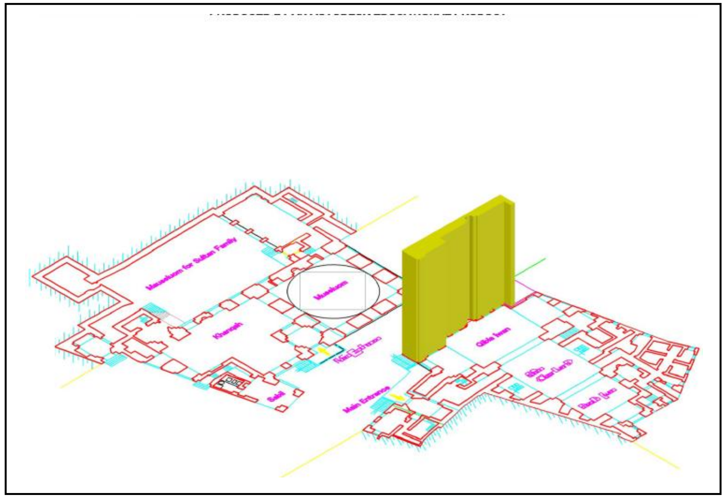
<u>5- Fifth Step:</u> Applying the Interior Space Design Rules.

These are the results of applying the interior space design rules in the Sultan Qalawun complex building:
* The qibla wall is square shaped and its height is equal to the building's total height.
* The four iwans are roofed and their height is equal to the building's total height.
* The entrance spaces are roofed and their height is equal to the building's total height.
* The mausoleum is covered with a dome.
* The design follows the opened courtyard type.

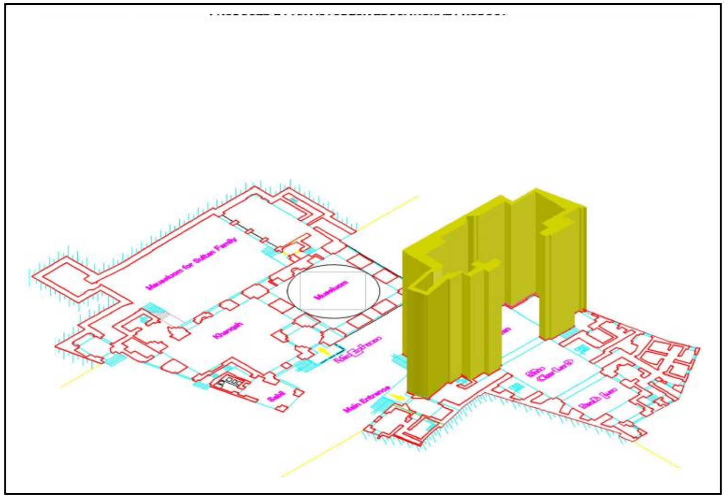
From the interior space design rules, the designer can determine the total height of the building. This is the first step in converting the two-dimensional plans which he had designed into three-dimensional spaces.

<u>6- Sixth Step:</u> Generating the Building Spaces' Disposition (The Design of the building in 3D).

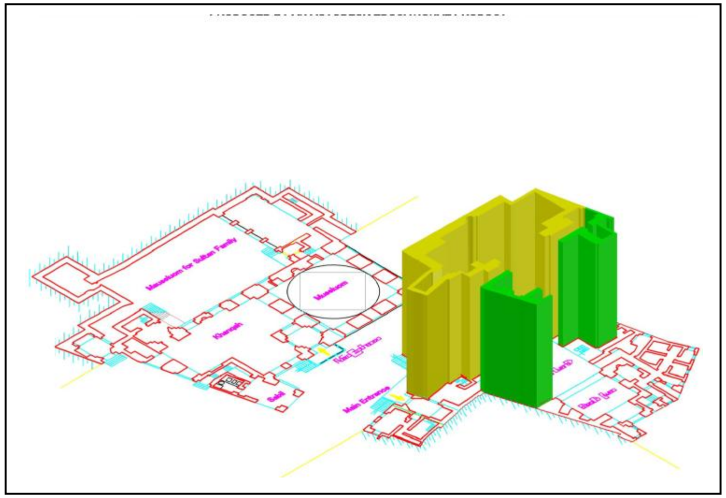
1- Constructing the Qibla Wall



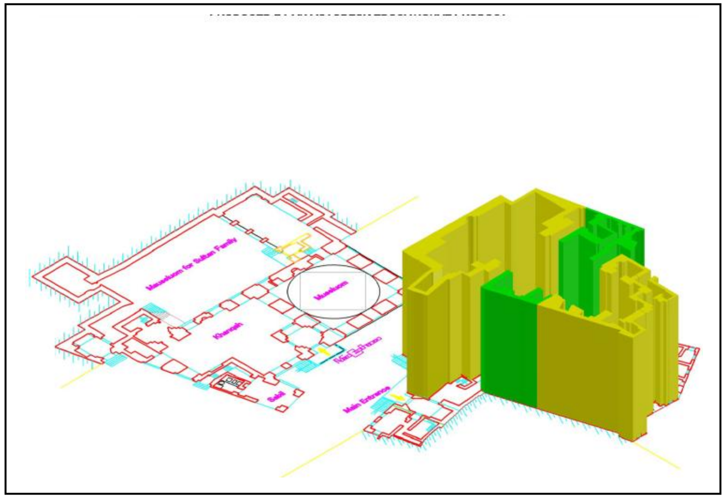
2- Completing the Qibla Iwan



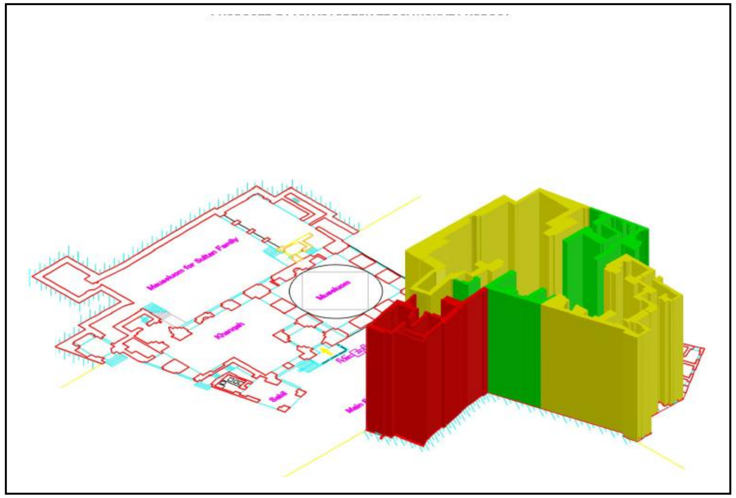
3- Constructing the Side Iwans



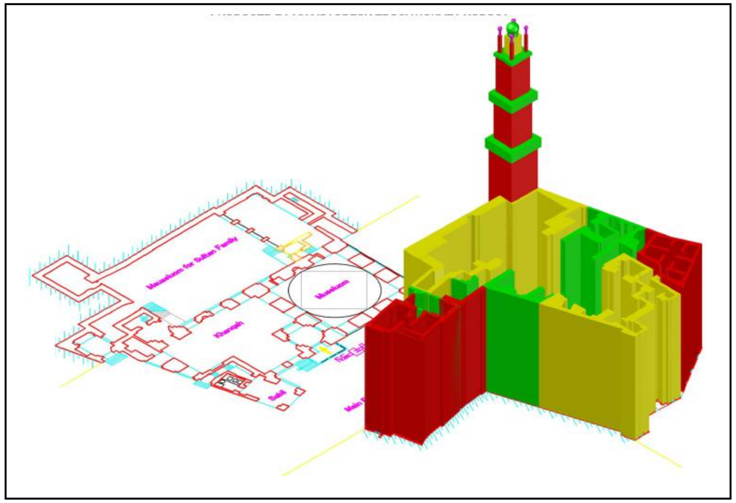
4- Constructing the South Iwan



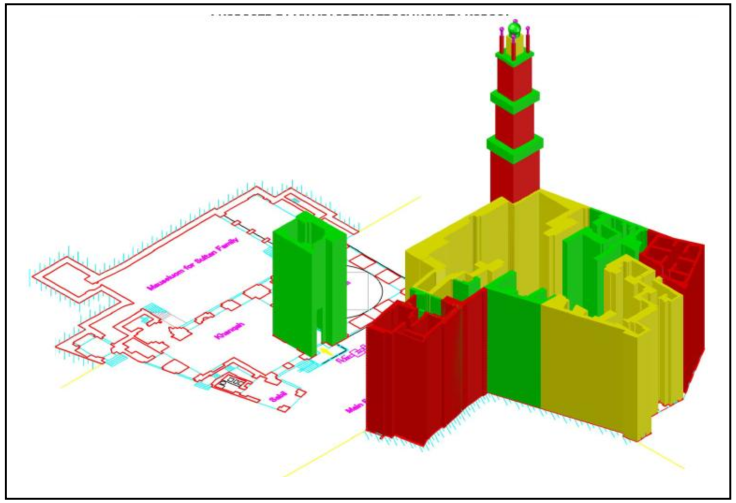
5- Constructing the Entrance and its Cells



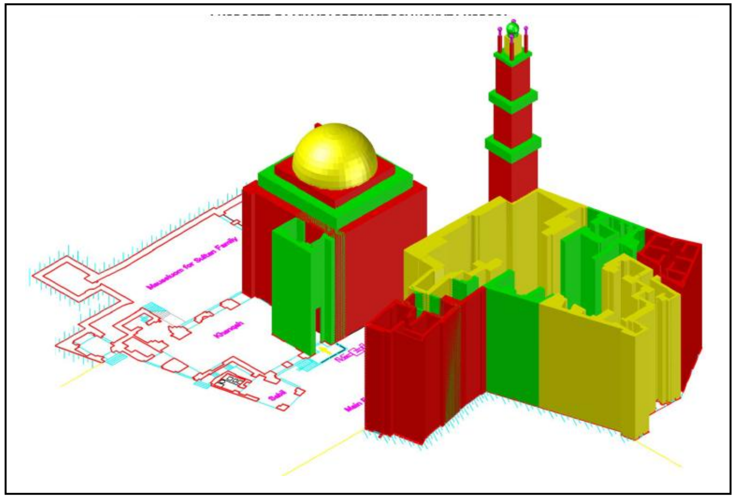
6- Constructing the Minaret



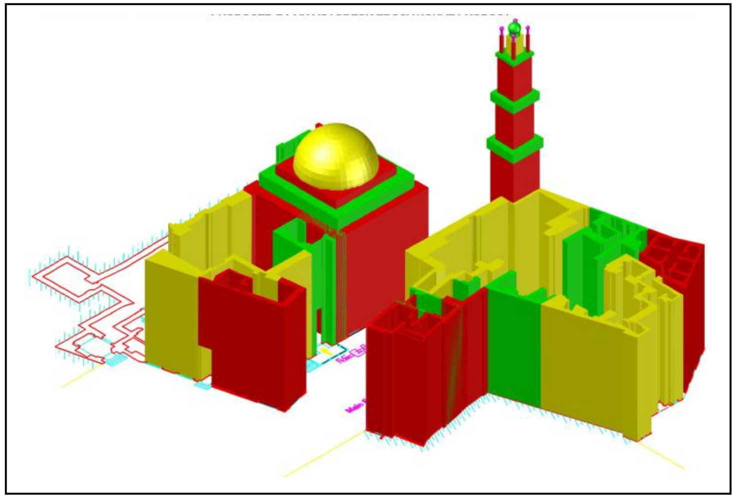
7- Constructing the Mausoleum Entrance



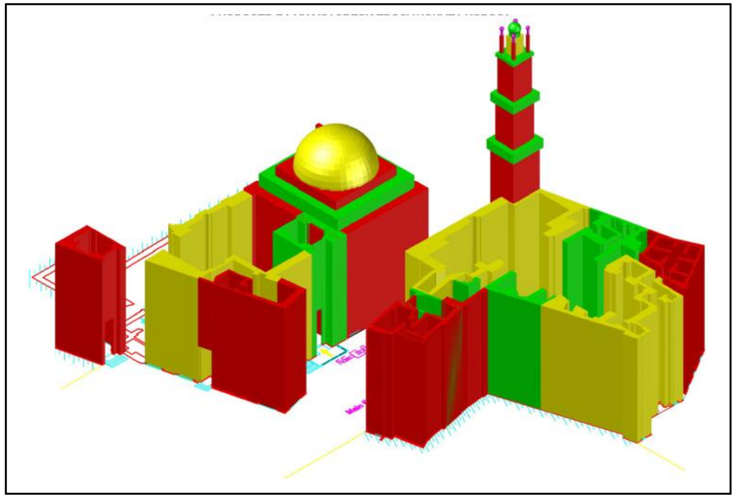
8- Constructing the Mausoleum



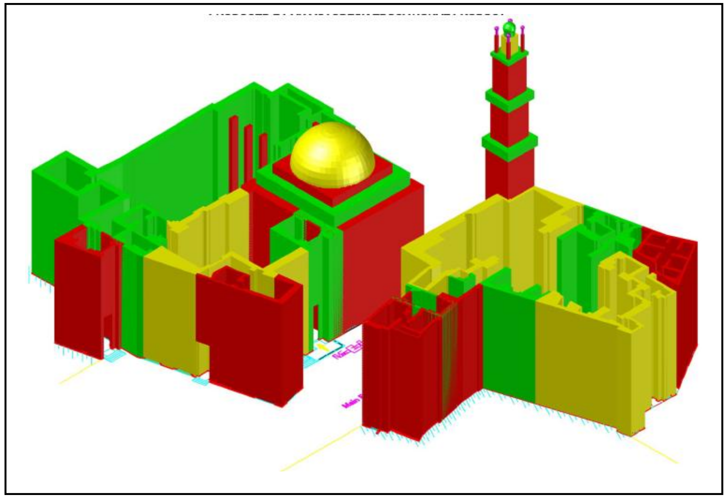
9- Constructing the Sabil and Completing the Khanqah Building



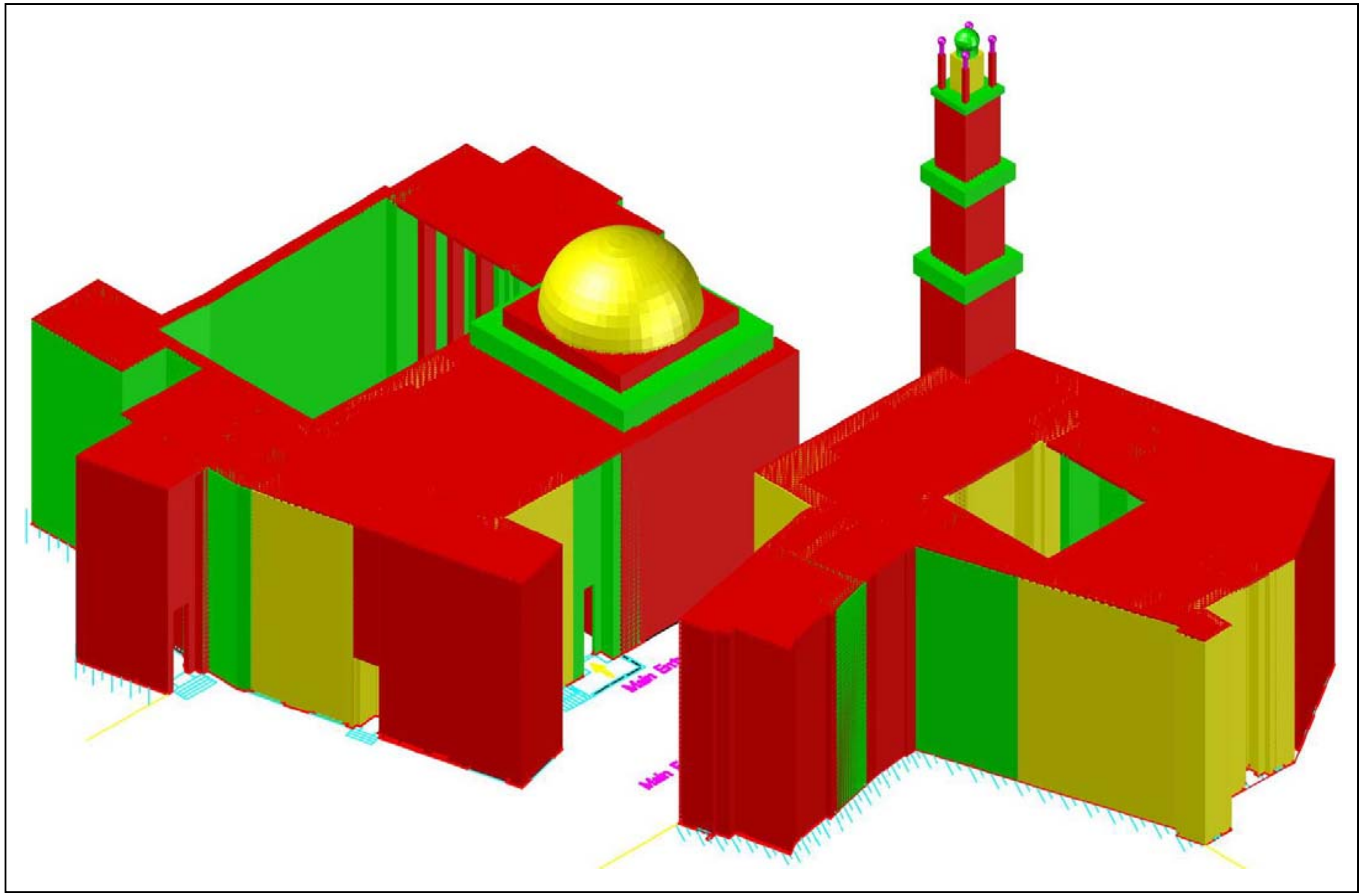
10- Constructing the Entrance to Attached Mausoleum



11- Completing the Attached Mausoleum



12- Roofing the Building



5.2.2. Applying the Geometric Generative Technique for the Facade Design in the Case-study Buildings

The geometric generative technique for facade design is applied to seven buildings in order to show the geometric order which governs the process of facade design in Mamluk madrasas, the case-study buildings as follows:

<u>Bahri Mamluk</u>

1- Madrasa of Sultan al-Mansur Qalawun (1284-5 A.D.)
2- Madrasa of Sultan Hasan (1356-63 A.D.)
3- Madrasa of Umm al-Sultan Sha‘ban, Khawand Baraka (1368-9 A.D.).

<u>Circassian Mamluk</u>

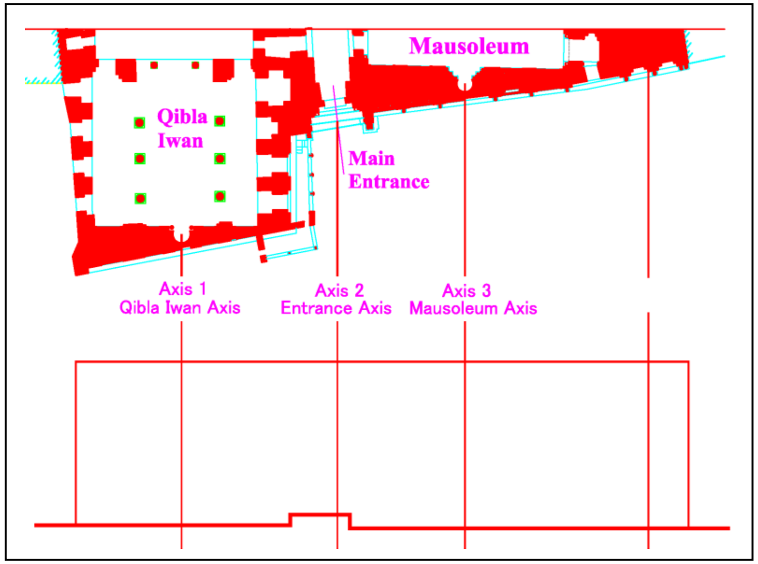
4- Madrasa of Sultan El Ashraf Barsbay (1423-4 A.D.)
5- Madrasa of Sultan Qaytbay (1472-4 A.D.)
6- Madrasa of Qadi Abu Bakr Muzhir (1479-80 A.D.).
7- Madrasa of Sultan Qansuah al-Ghuri (1502-4 A.D.)

5.2.2.1 Madrasa of Sultan Qalawun (1284-5 A.D.)

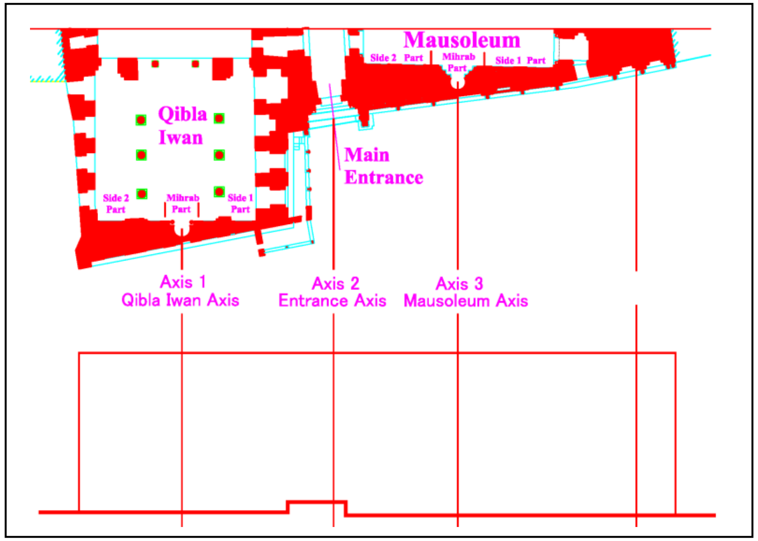
The geometric generative technique steps for generating facade design are applied in Madrasa of Sultan Qalawun to show how the early Mamluk architect produced the building facade design, according to a geometrical order control and motor his thinking. The steps are as follows:

1- Determine the façade boundary and its total height

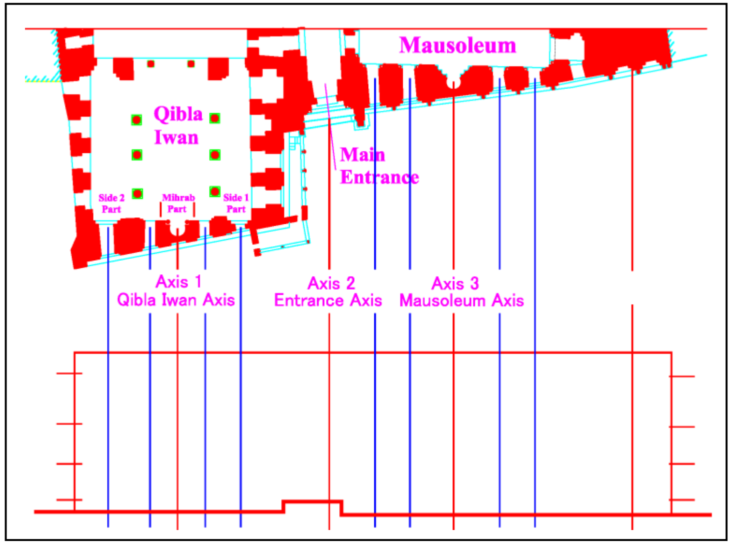
2- Add the main vertical axes of the facade



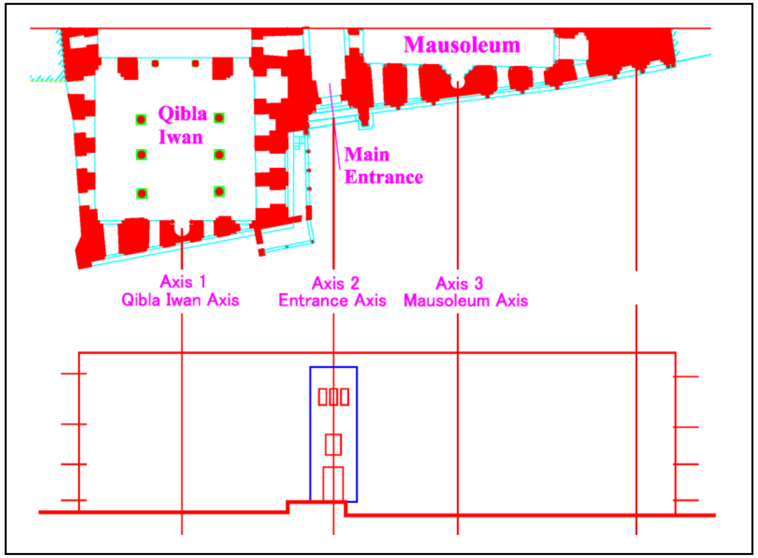
3- Divide the qibla wall into three major parts



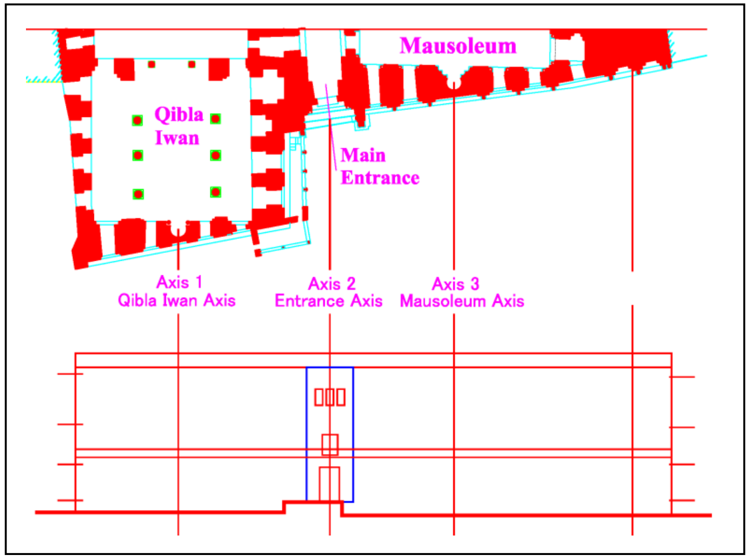
4- Add the sub-axes around the main axes



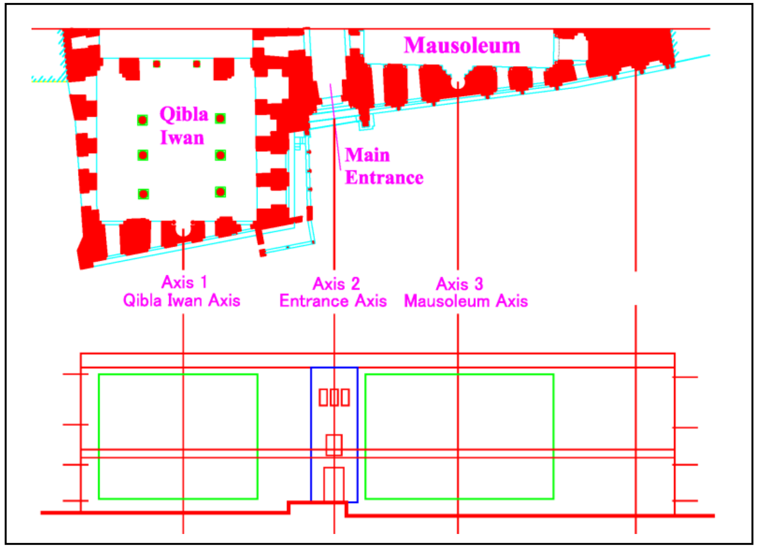
5- Determine the different floor levels



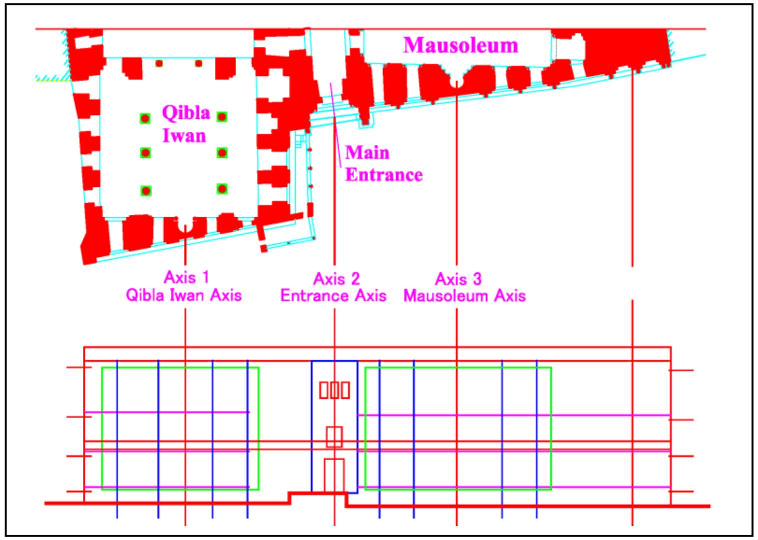
6- Add the entrance door and design the entrance panel



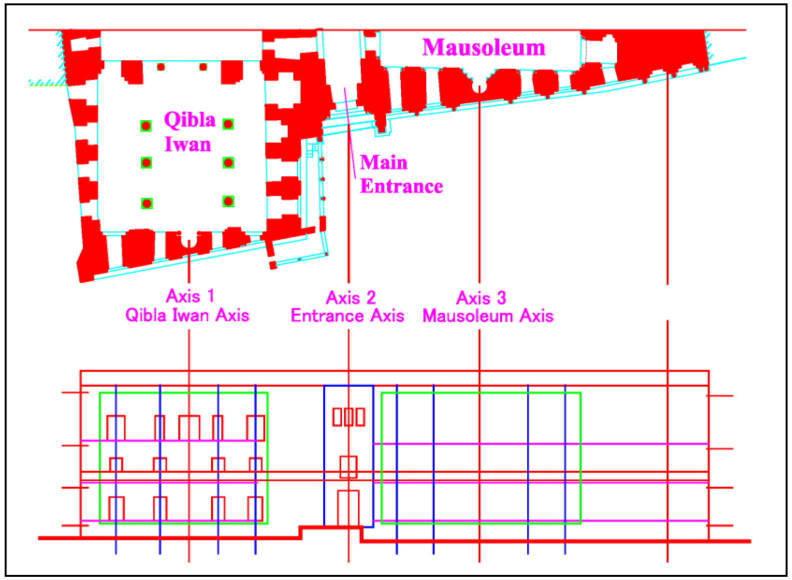
7- Determine the facade decoration elements position



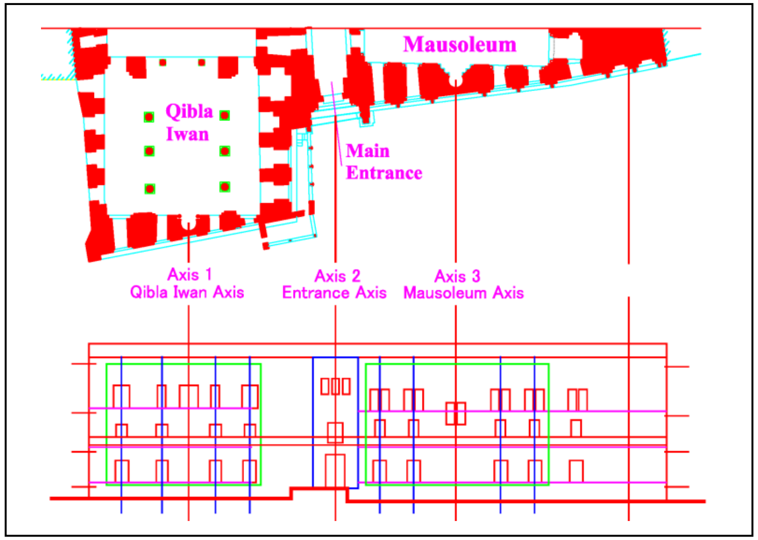
8- Add the facade main squares



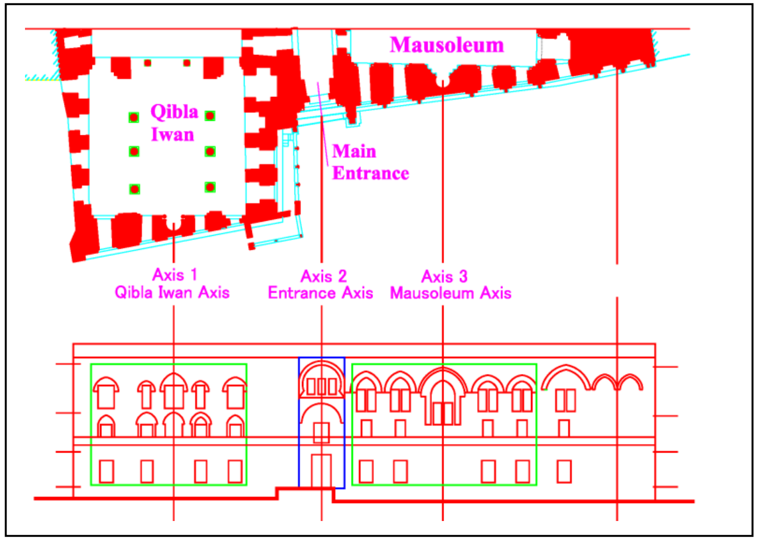
9- Determine the windows horizontal axes and identify the window's height on all levels



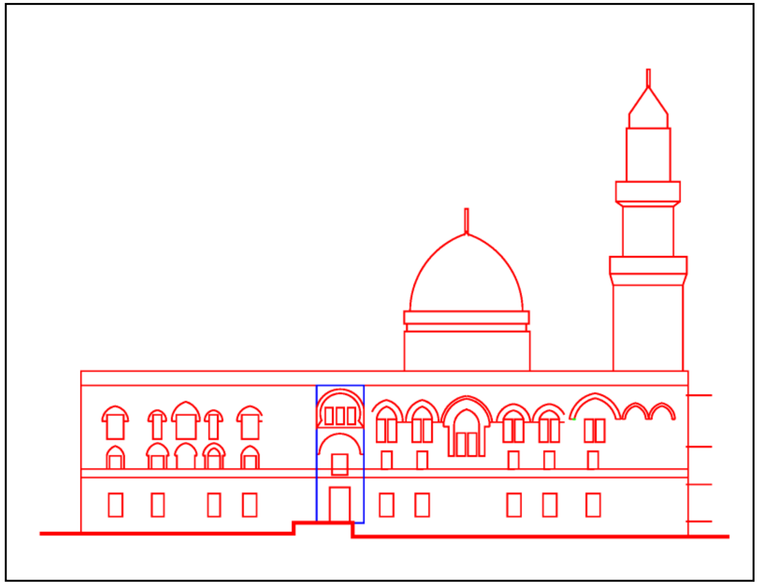
10- Complete the facade windows



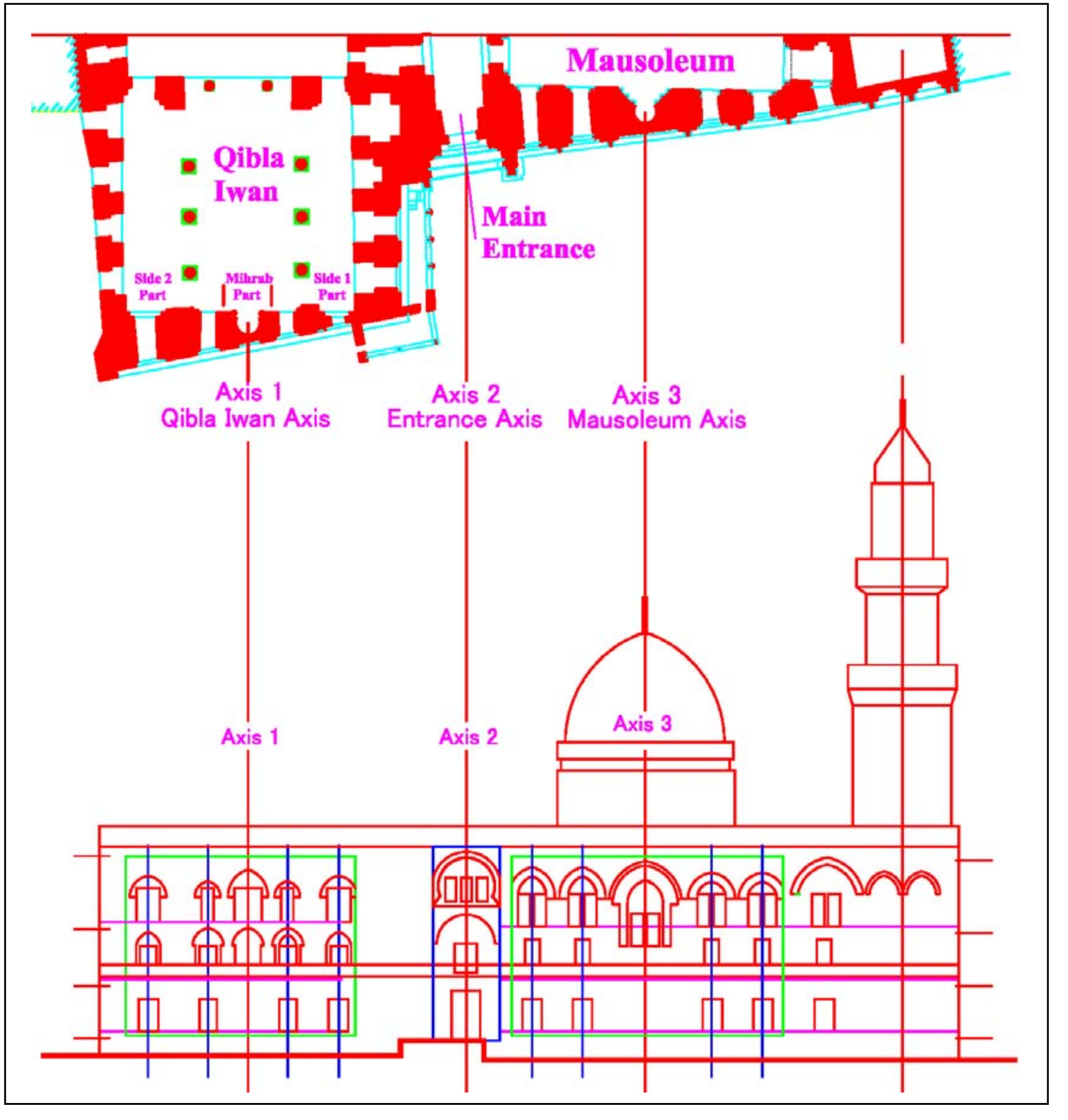
11- Add the facade decoration around the windows



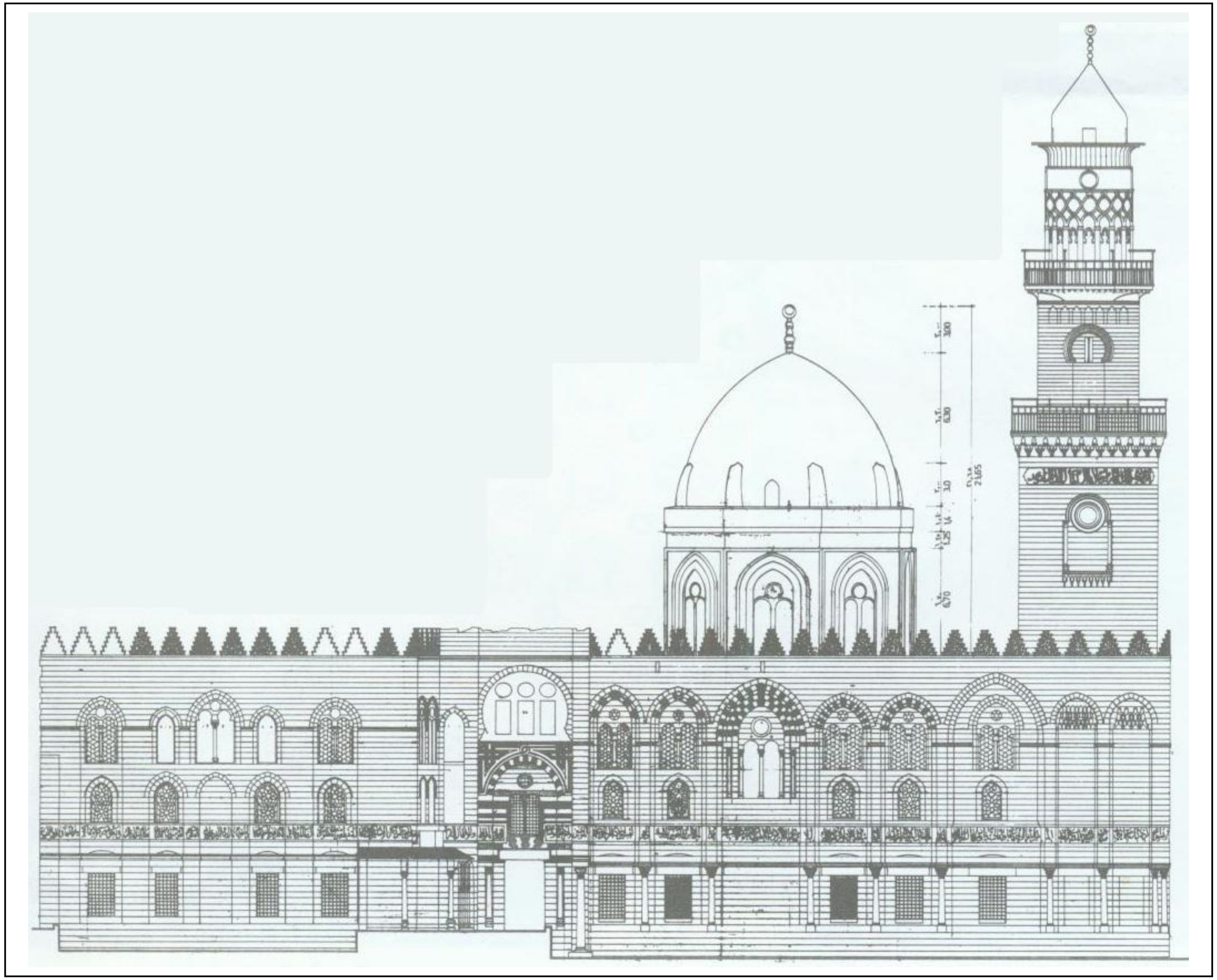
12- Complete the facade design (placing the minaret and the mausoleum's dome)



13- Make final design of the facade with the hidden geometric order



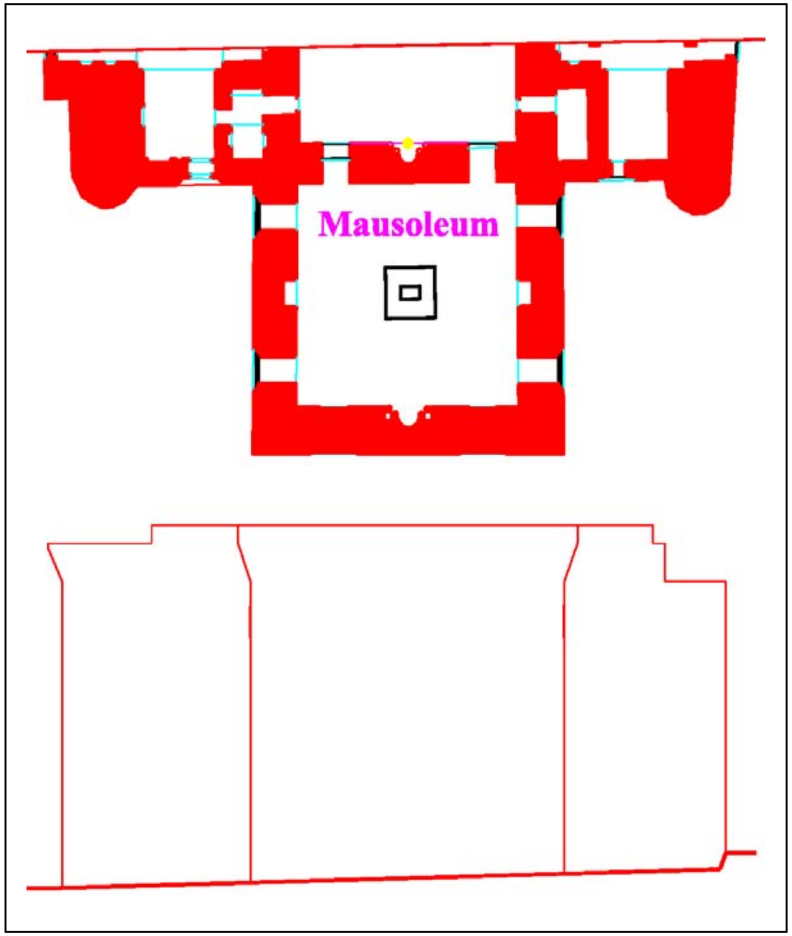
14- Determine final shape of the facade



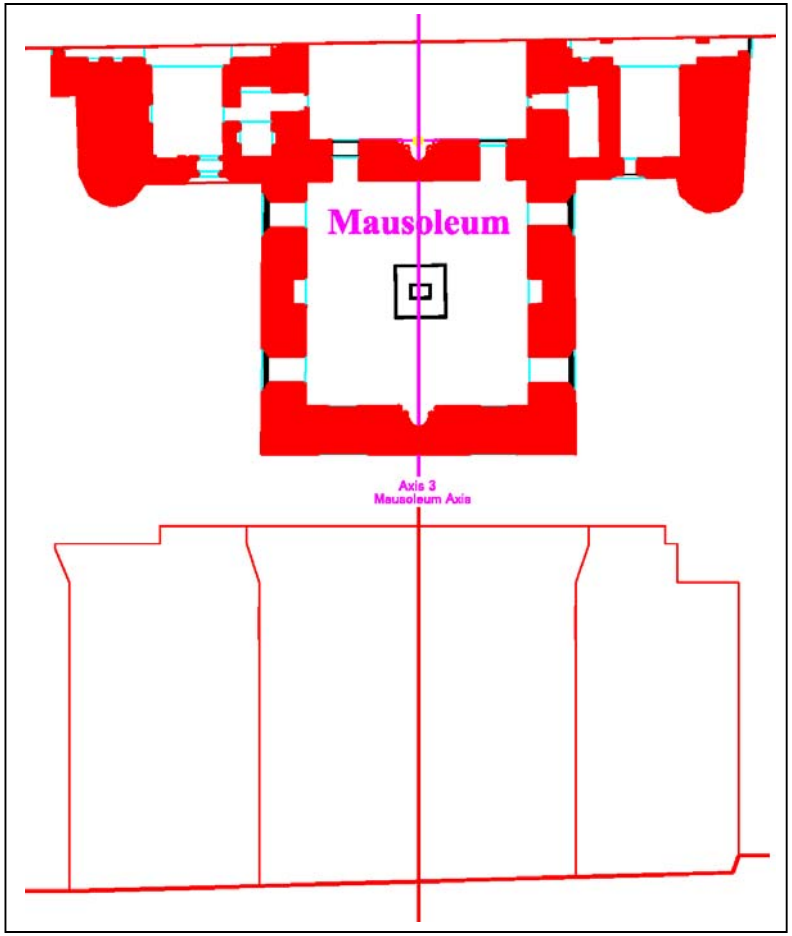
5.2.2.2 Madrasa of Sultan Hassan (1356-63 A.D.)

The Geometric Generative Technique steps for generating facade design are applied in Madrasa of Sultan Hassan to show how the early Mamluk architect produced the building facade design, according to a geometrical order control and motor his thinking. The steps are as follows:

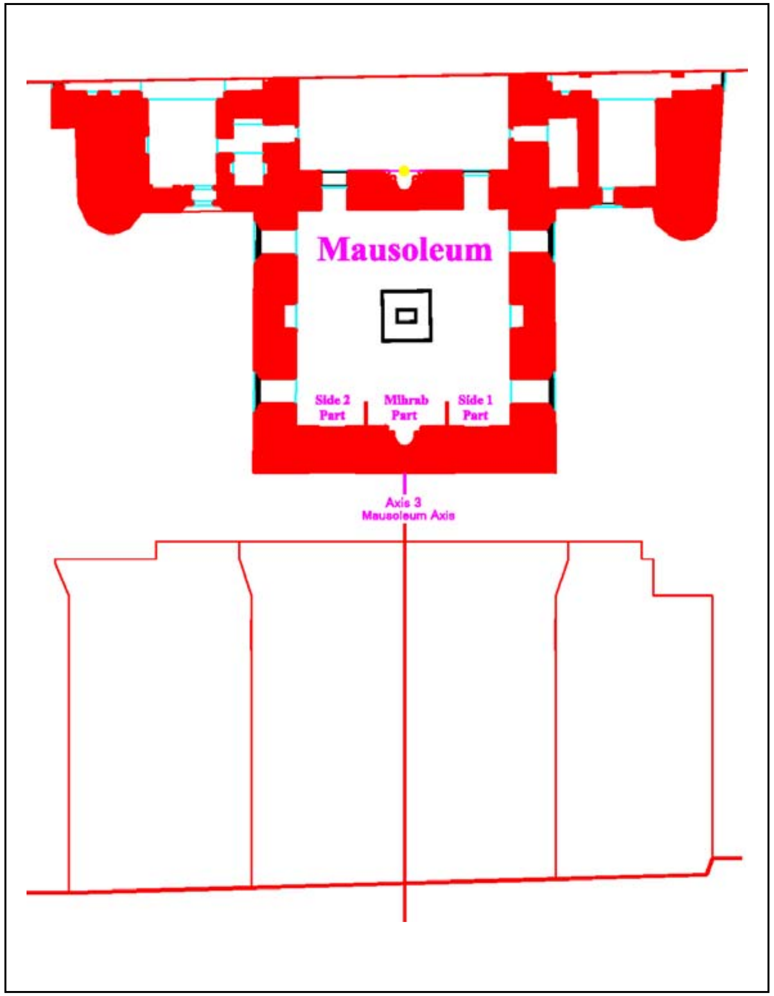
1- Determine the facade boundary and its total height



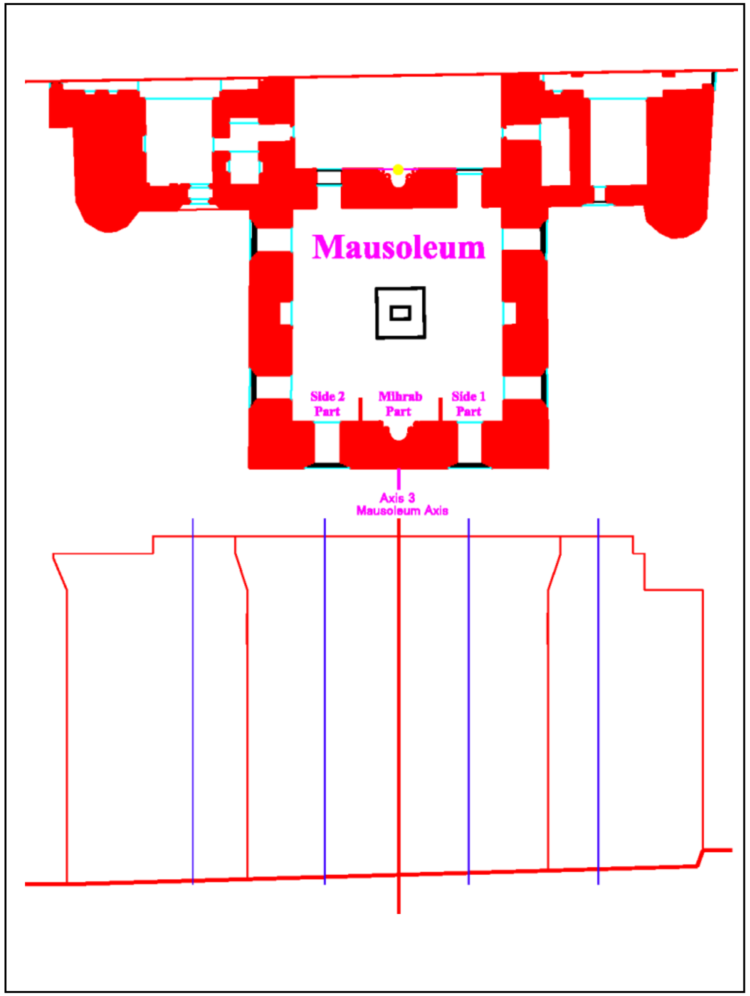
2- Add the main vertical axes of the facade



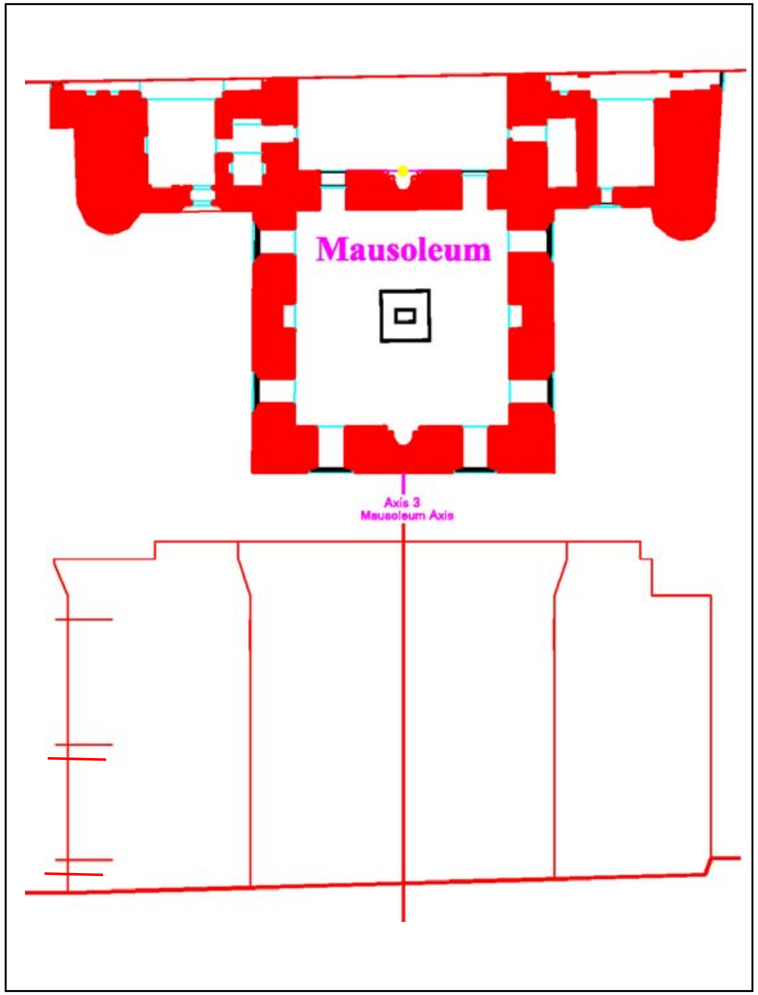
3- Divide the qibla wall into three major parts



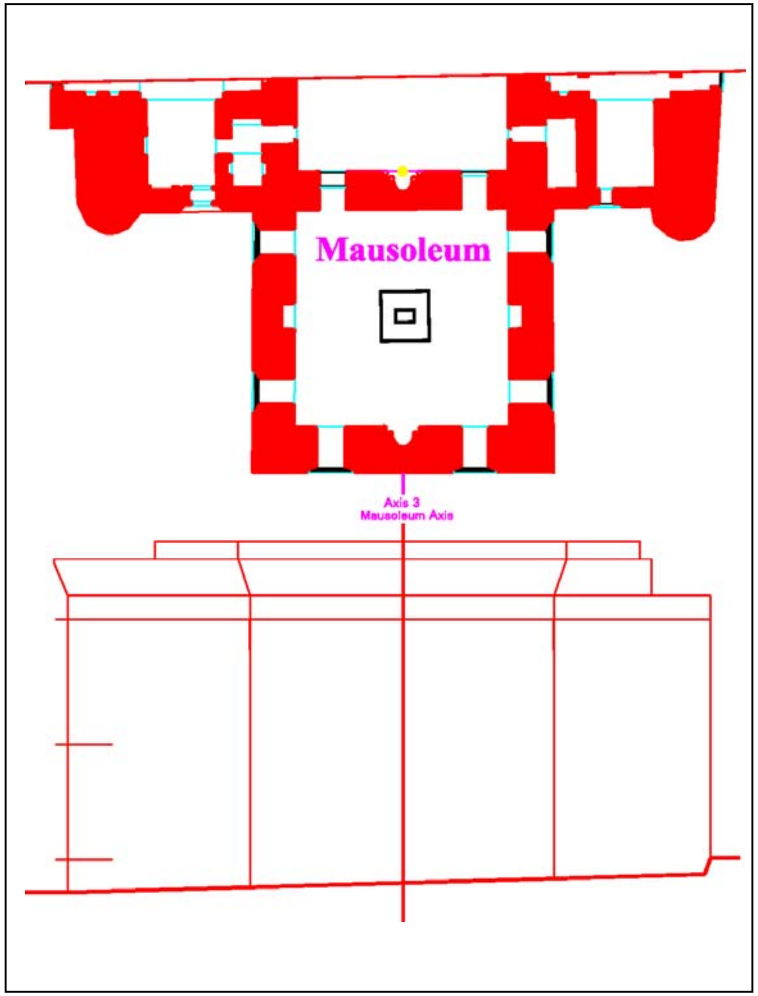
4- Add the sub-axes around the main axes



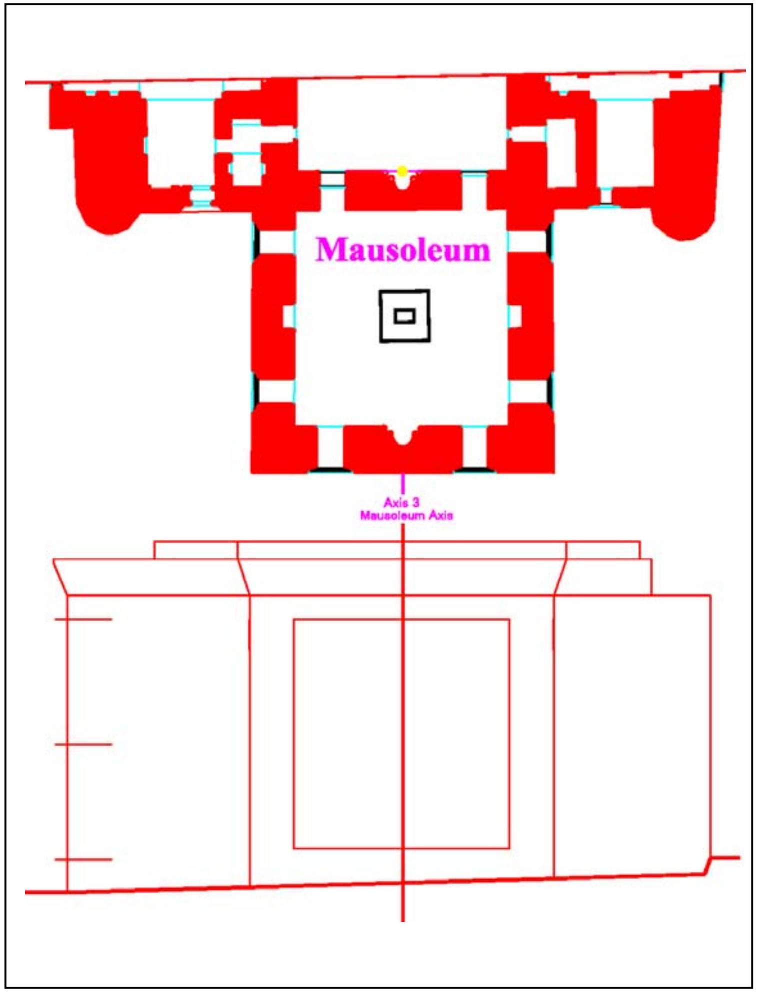
5- Determine the different floor levels



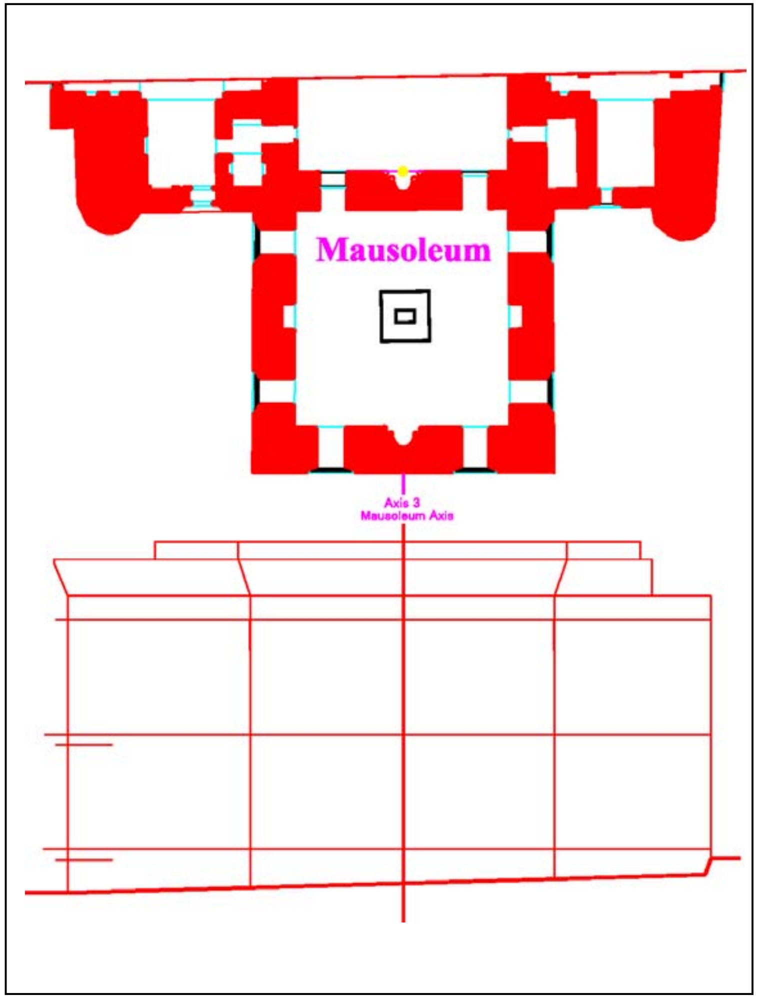
6- Determine the facade decoration elements position



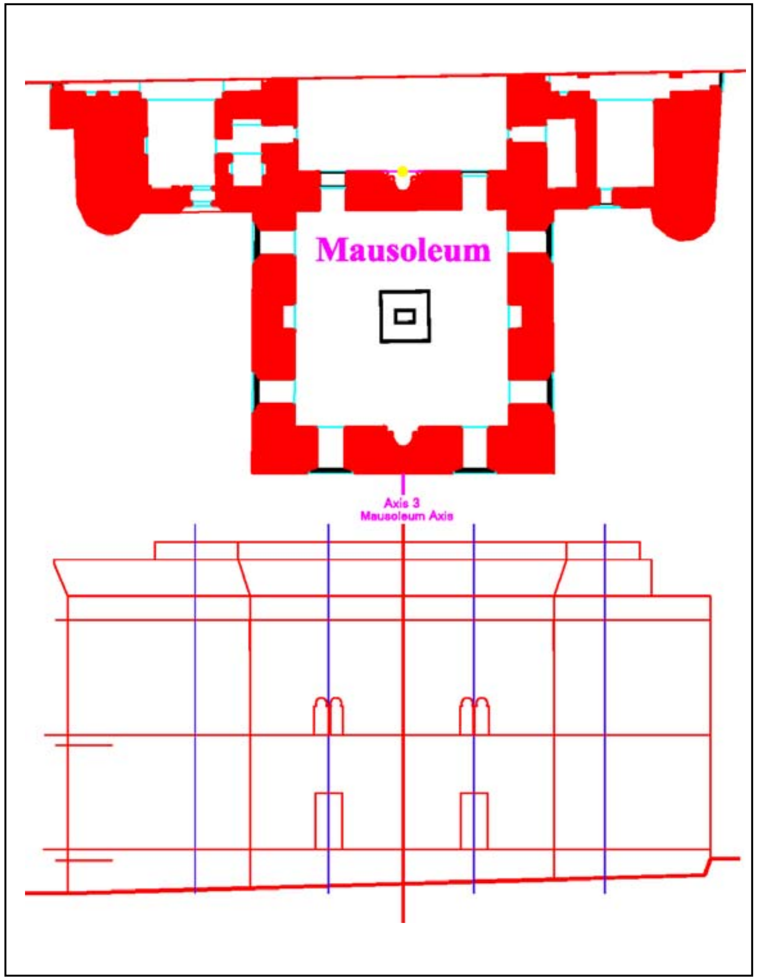
7- Add the facade's main squares



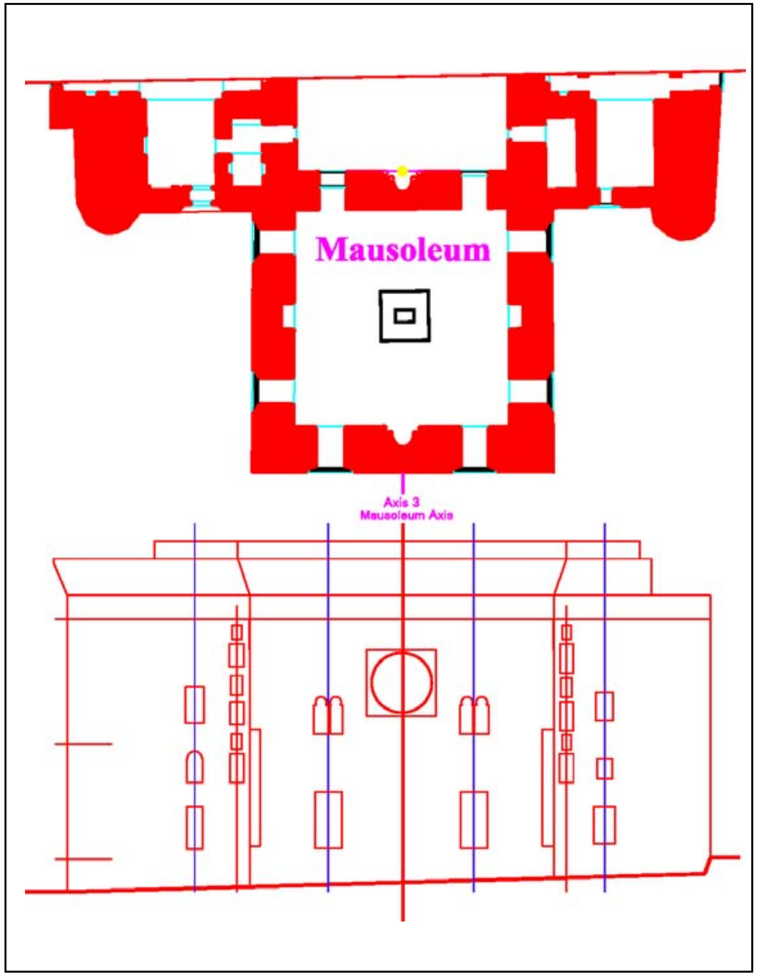
8- Determine the windows horizontal axes



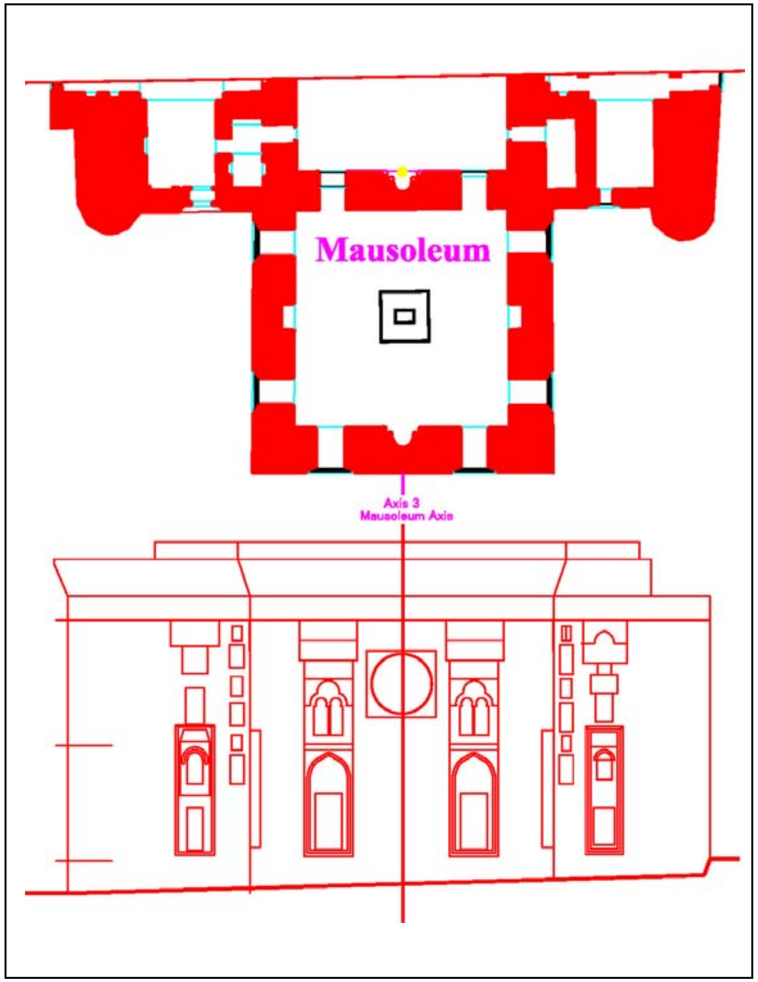
9- Identify the window's height in all levels



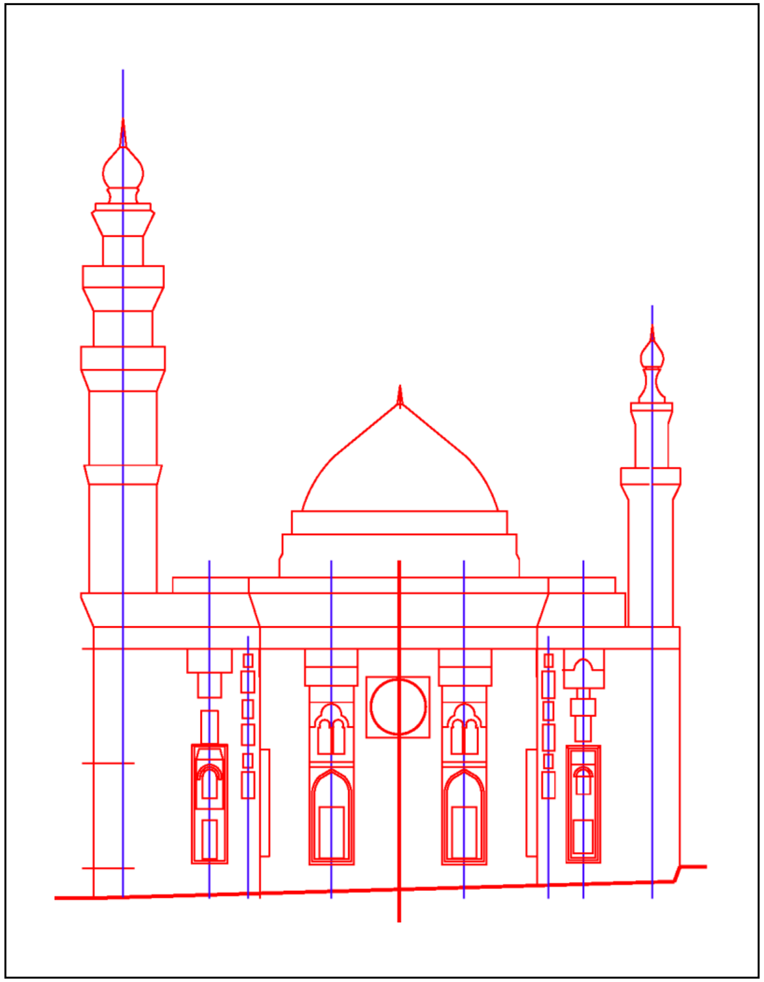
10- Complete the facade windows



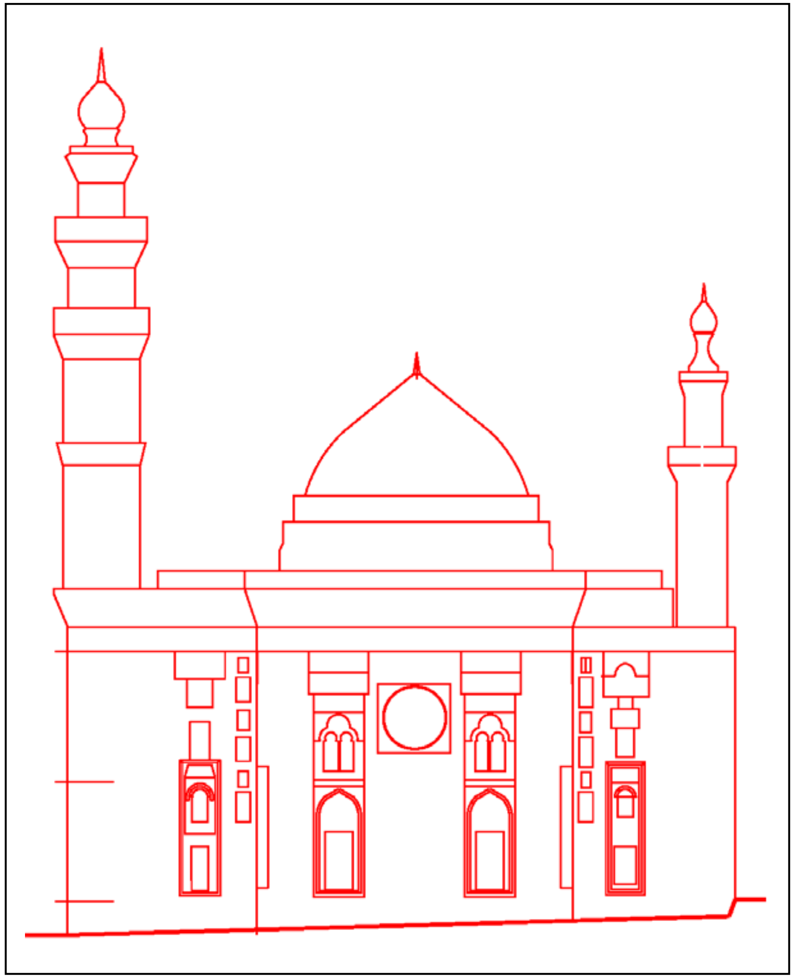
11- Add the facade decoration around the windows



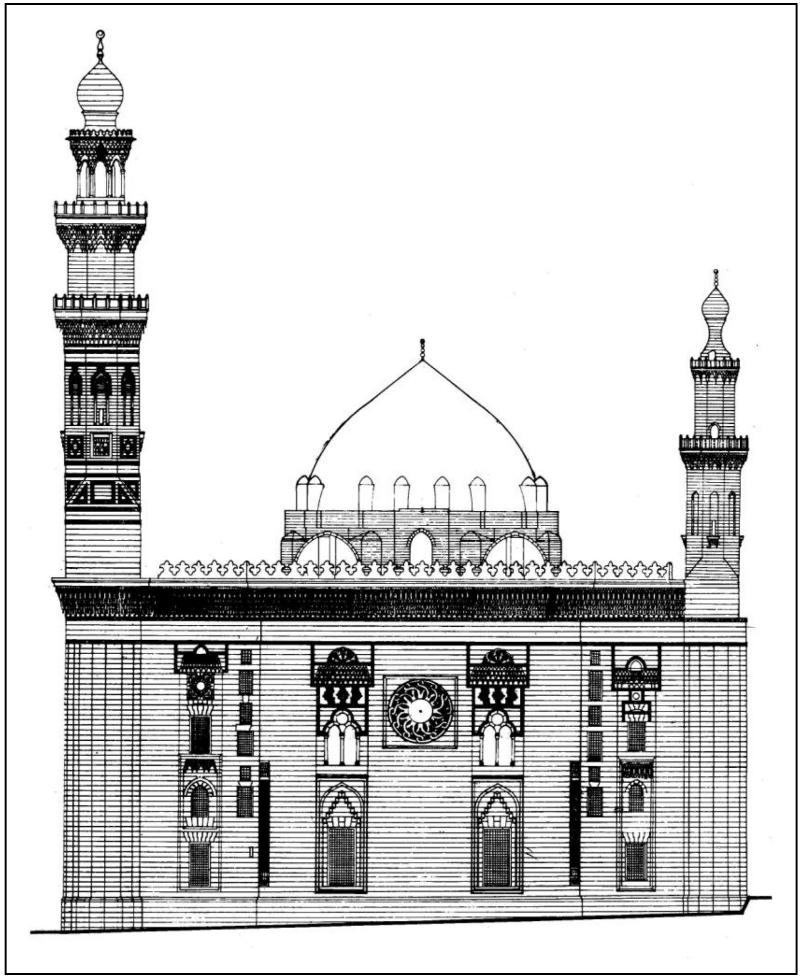
12- Complete the facade design (placing the minaret and the mausoleum's dome)



13- Make final Design of the facade



14- Determine final shape of the facade

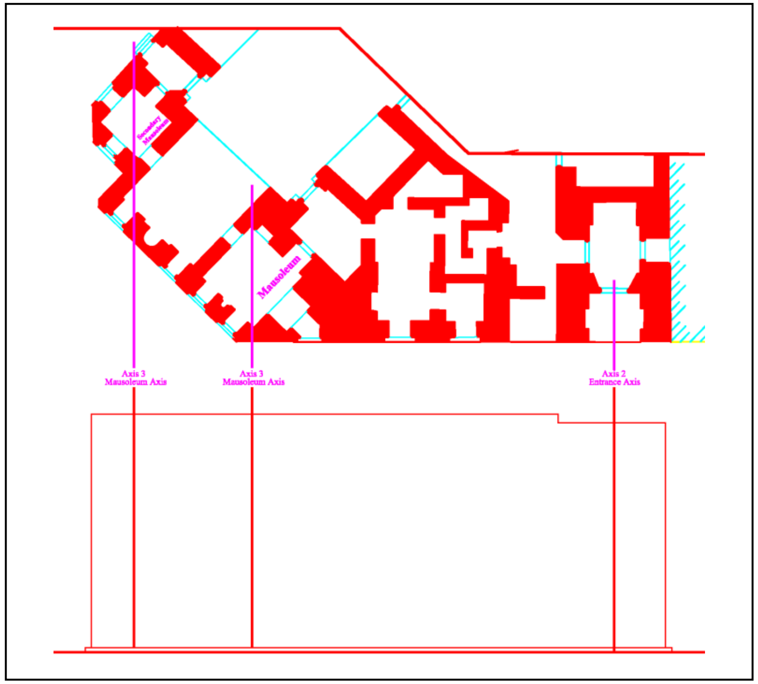


5.2.2.3 Madrasa of Umm al-Sultan Sha‘ban (1368-9 A.D.)

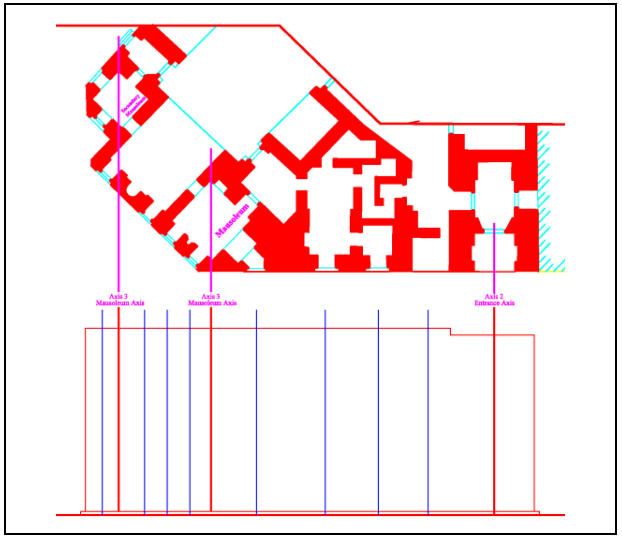
The geometric generative technique steps for generating facade design are applied in Madrasa of Umm al-Sultan Sha’ban to show how the early Mamluk architect produced the building facade design according to a geometrical order control and motor his thinking. The steps are as follows:

1- Determine the facade boundary and its total height

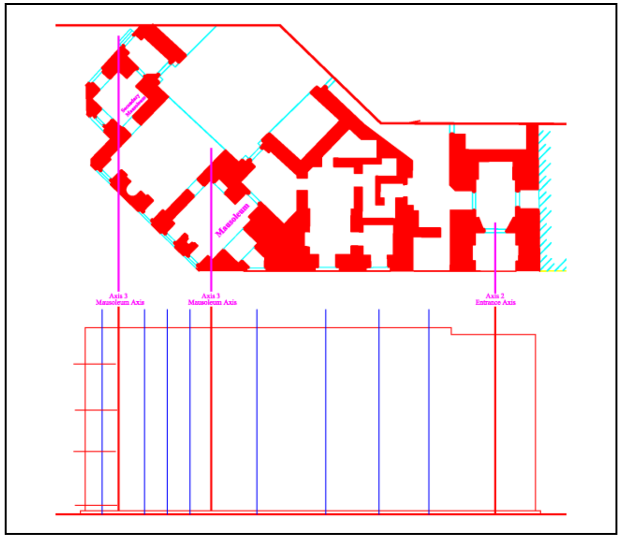
2- Add the main vertical axes of the facade



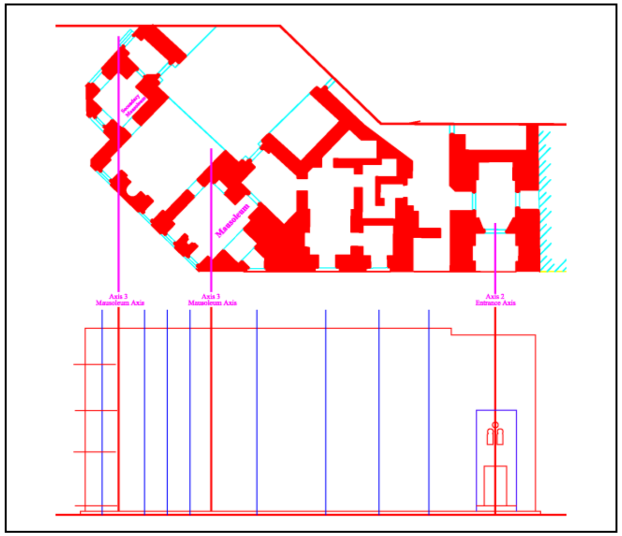
3- Add the sub-axes around the main axes



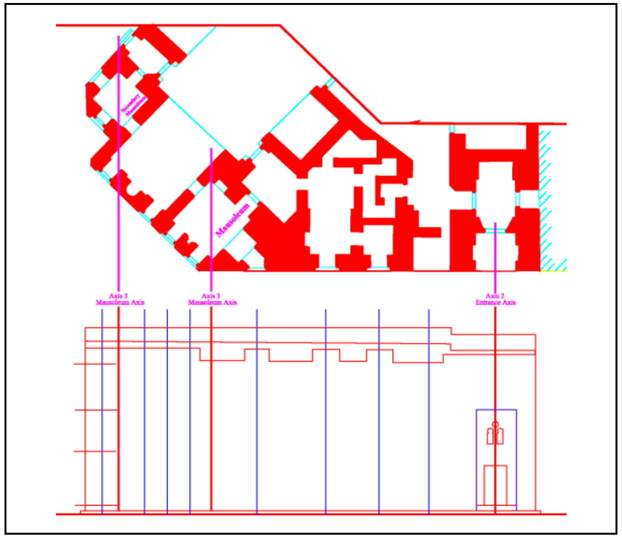
4- Determine the different floor levels



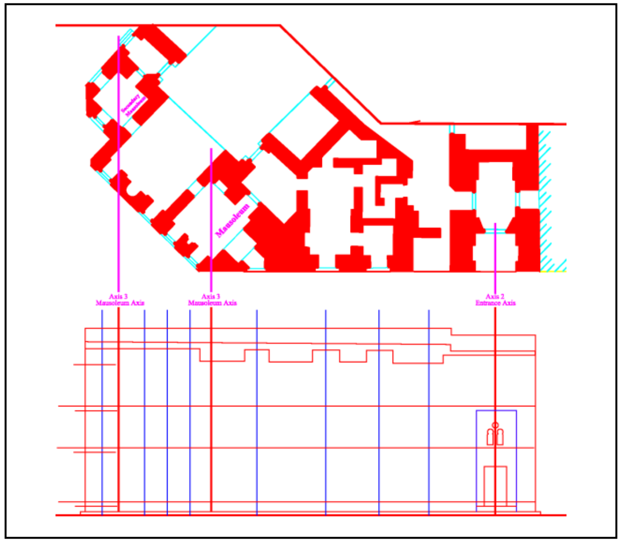
5- Add the entrance door and design the entrance panel



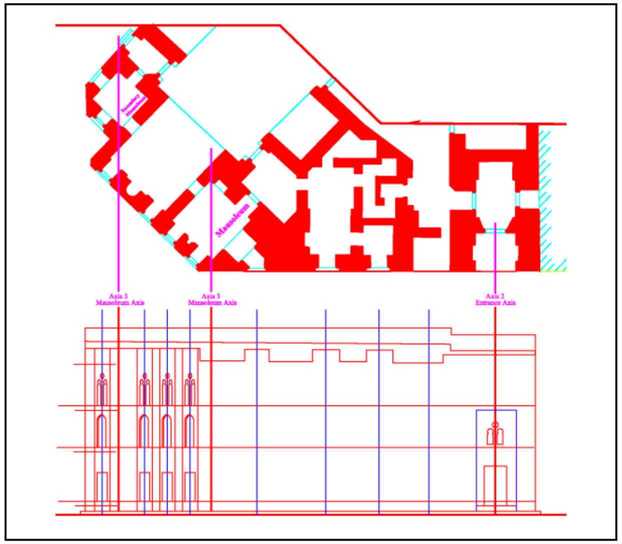
6- Determine the facade decoration elements position



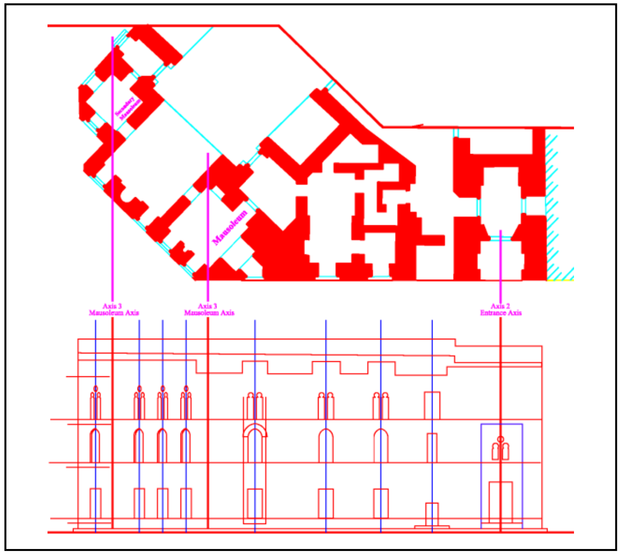
7- Determine the windows horizontal axes



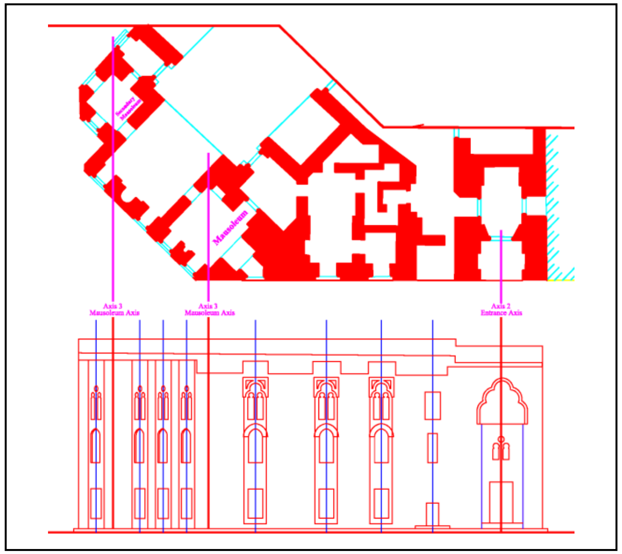
8- Identify the window’s height in all levels



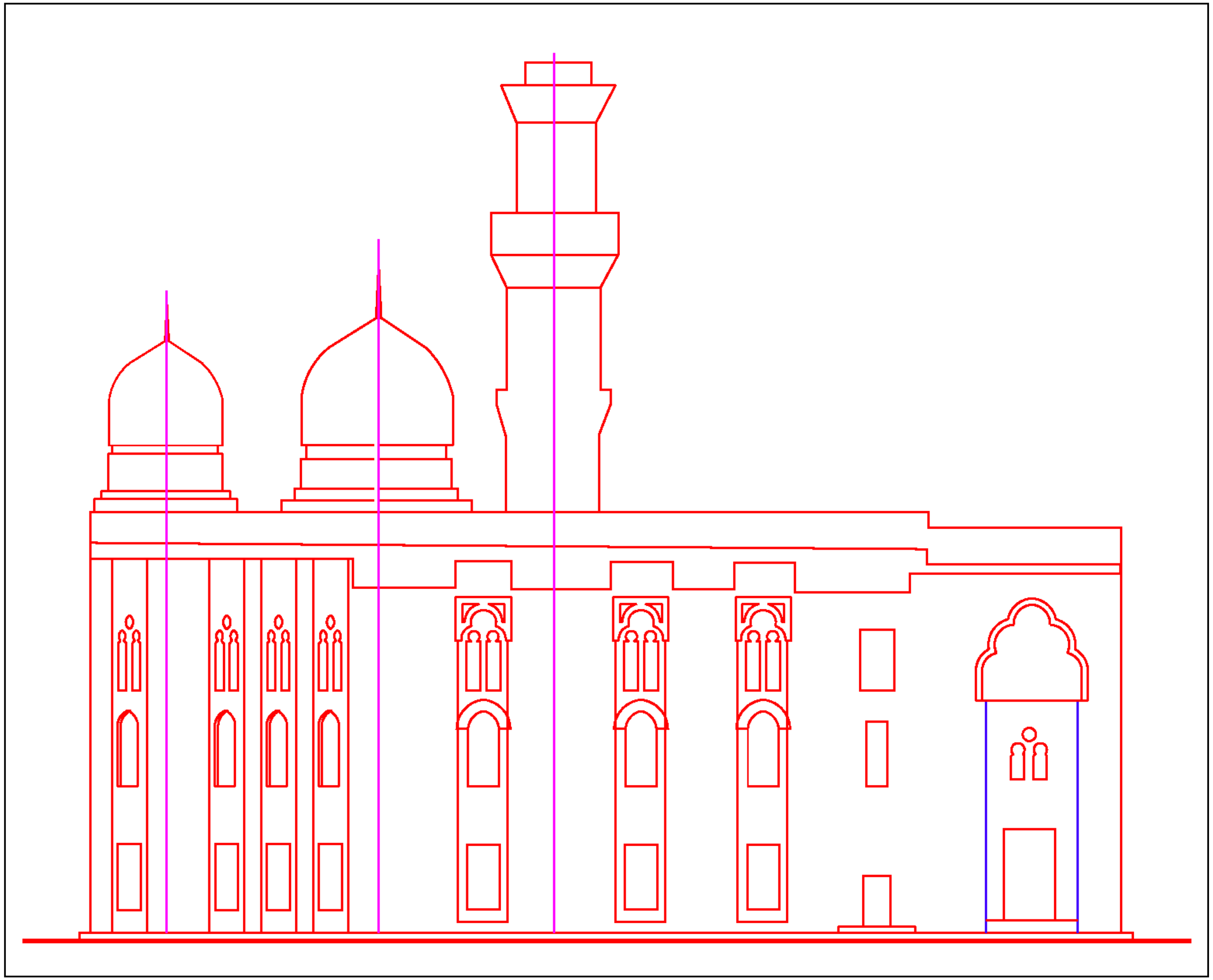
9- Completing the facade windows



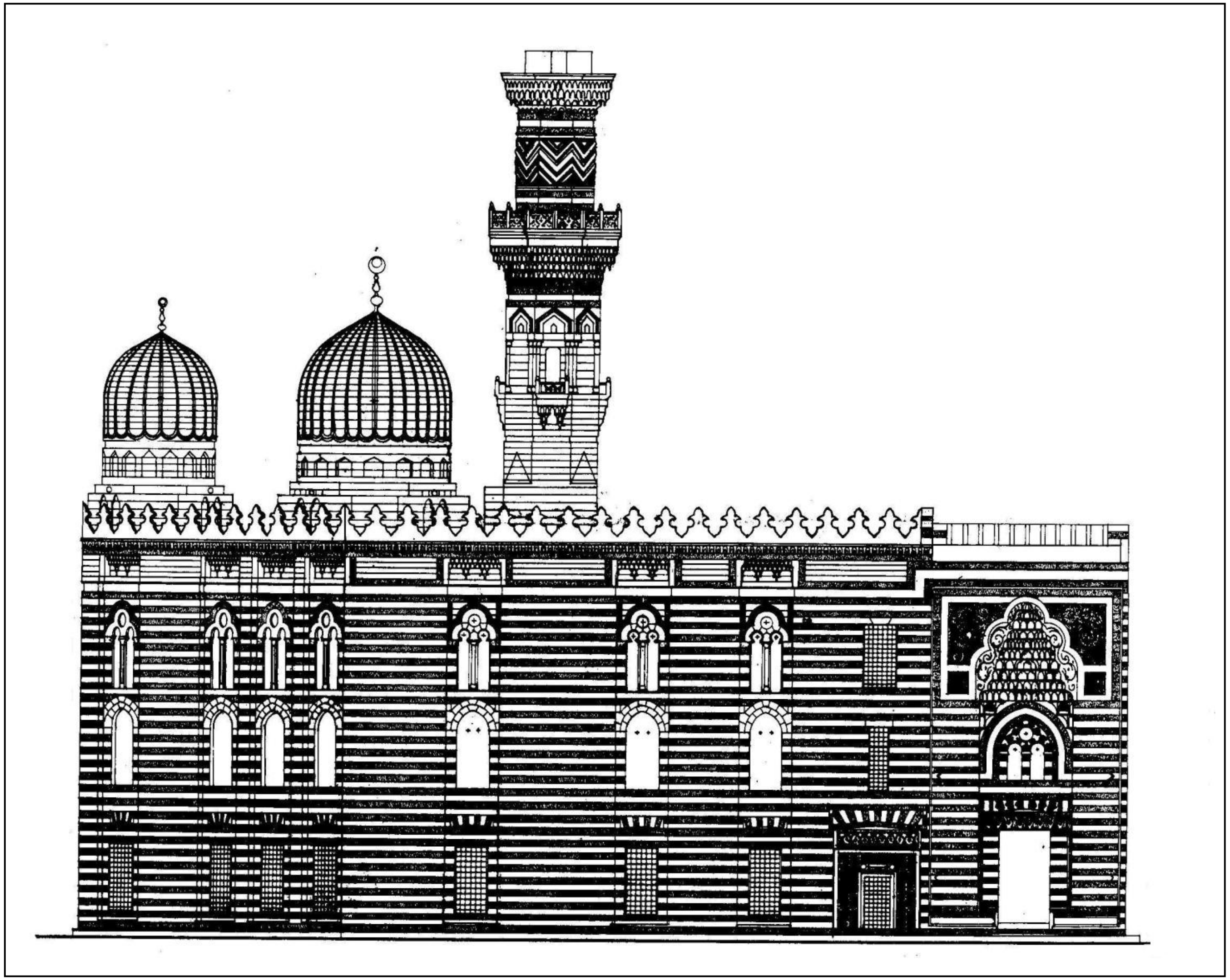
10- Add the facade decoration around the windows



11- Complete the facade design (placing the minaret and the mausoleum's dome)



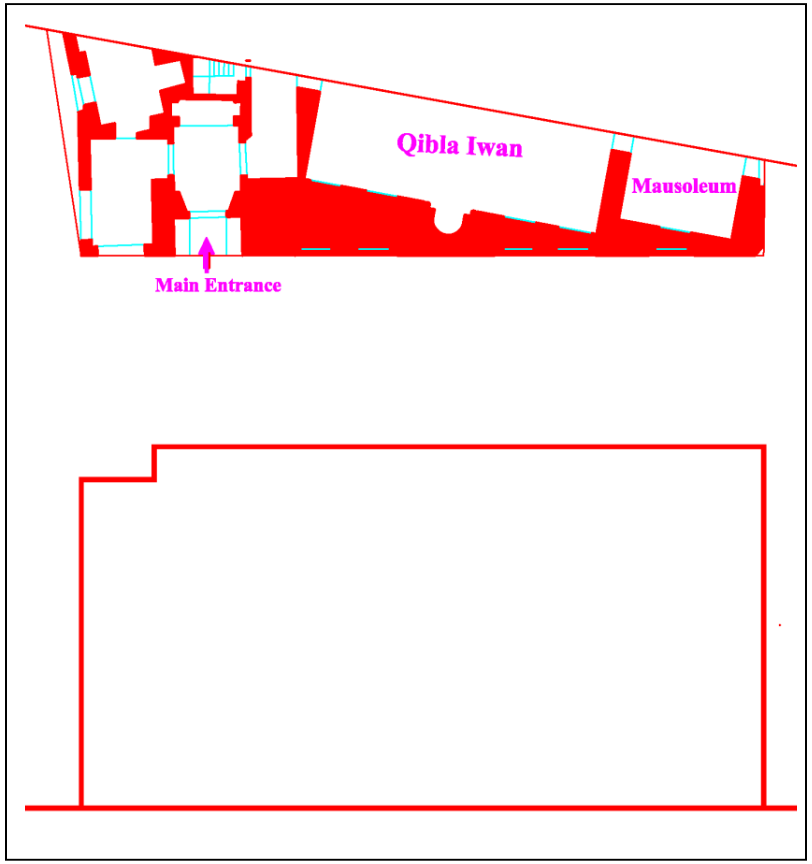
12- Make final shape of the facade



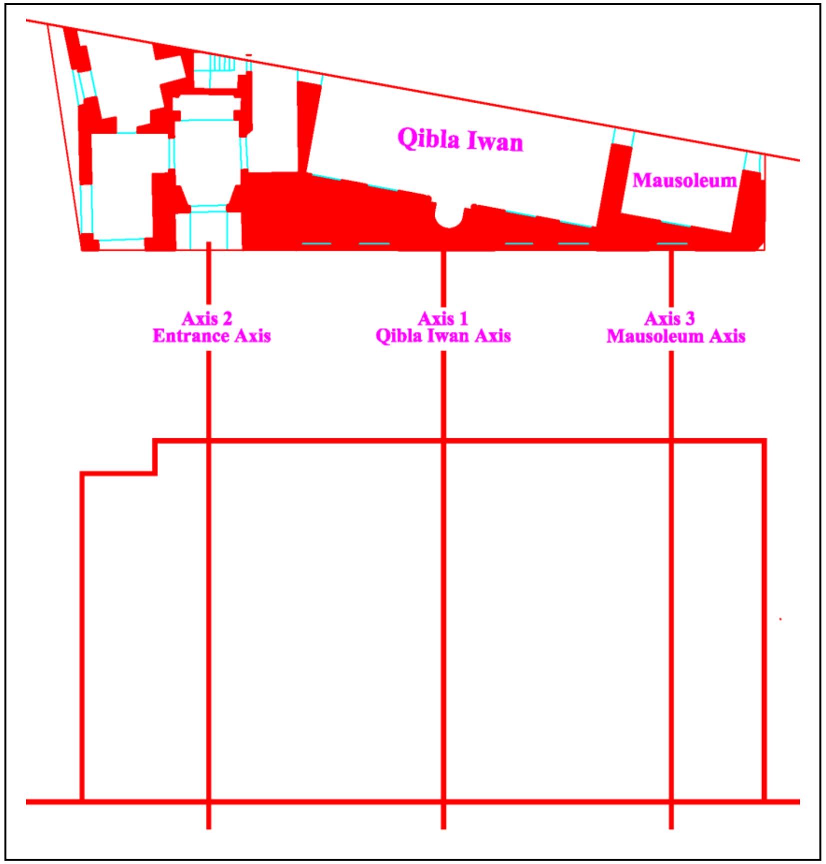
5.2.2.4 Madrasa of Sultan El Ashraf Barsbay (1423-4 A.D.)

The geometric generative technique steps for generating façade design are applied in the Madrasa of Sultan El Ashraf Barsbay building to show how the early Mamluk architect produced the building façade design according to a geometrical order control and motor his thinking. The steps are as follows:

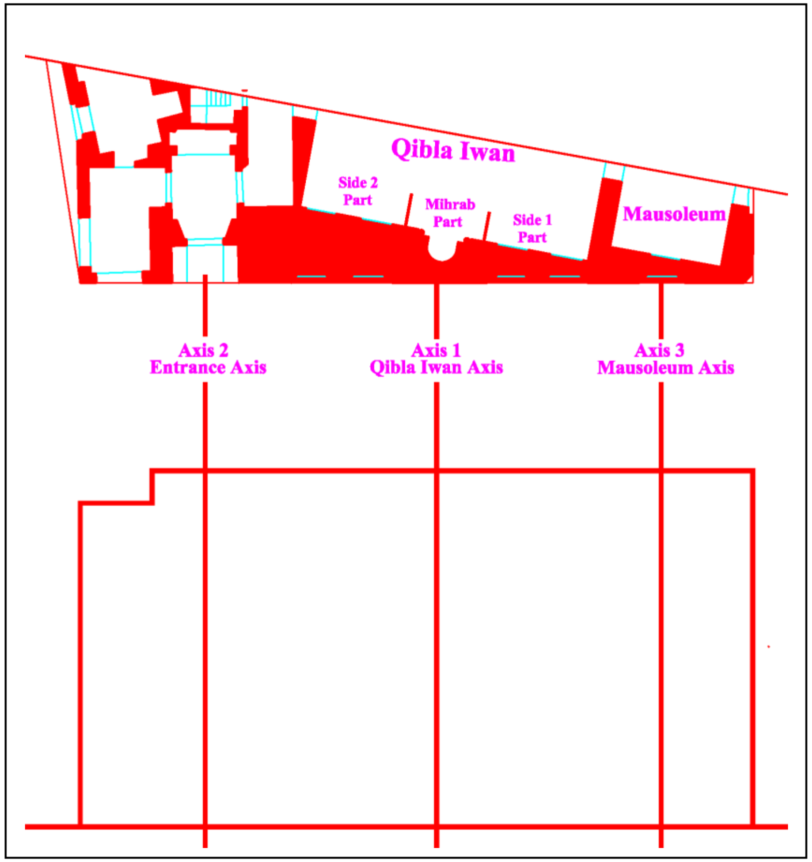
1- Determine the facade boundary and its total height



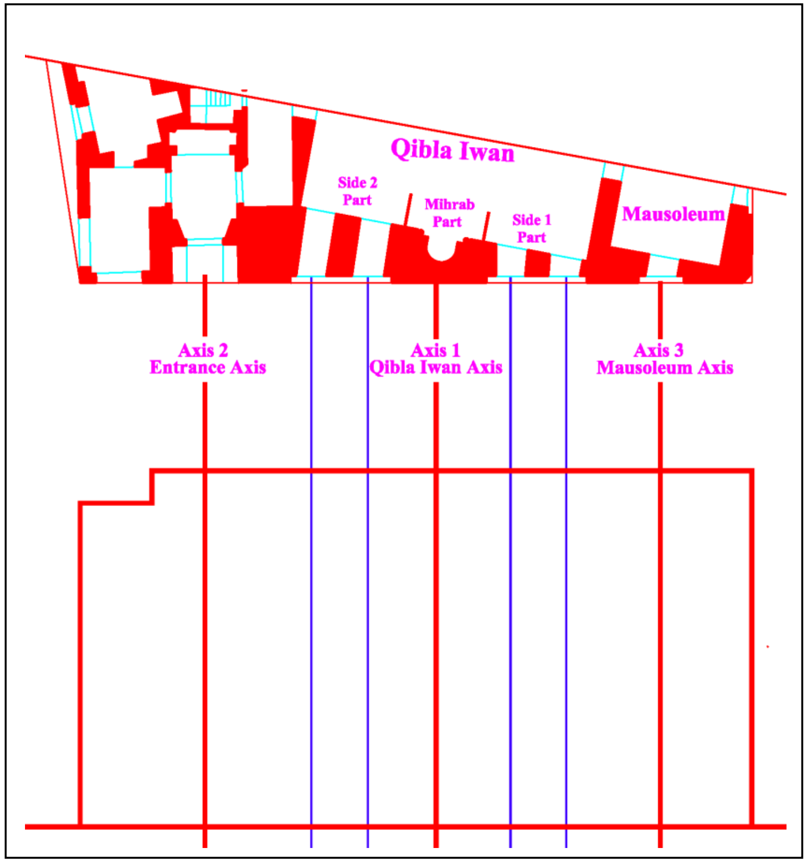
2- Add the main vertical axes of the facade



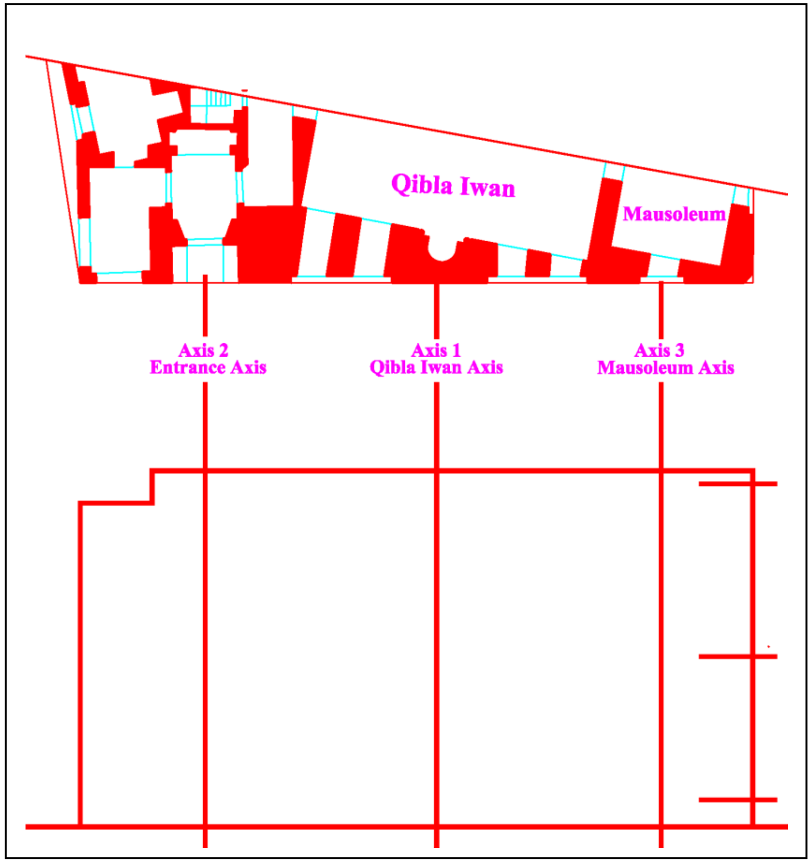
3- Divide the qibla wall into three major parts



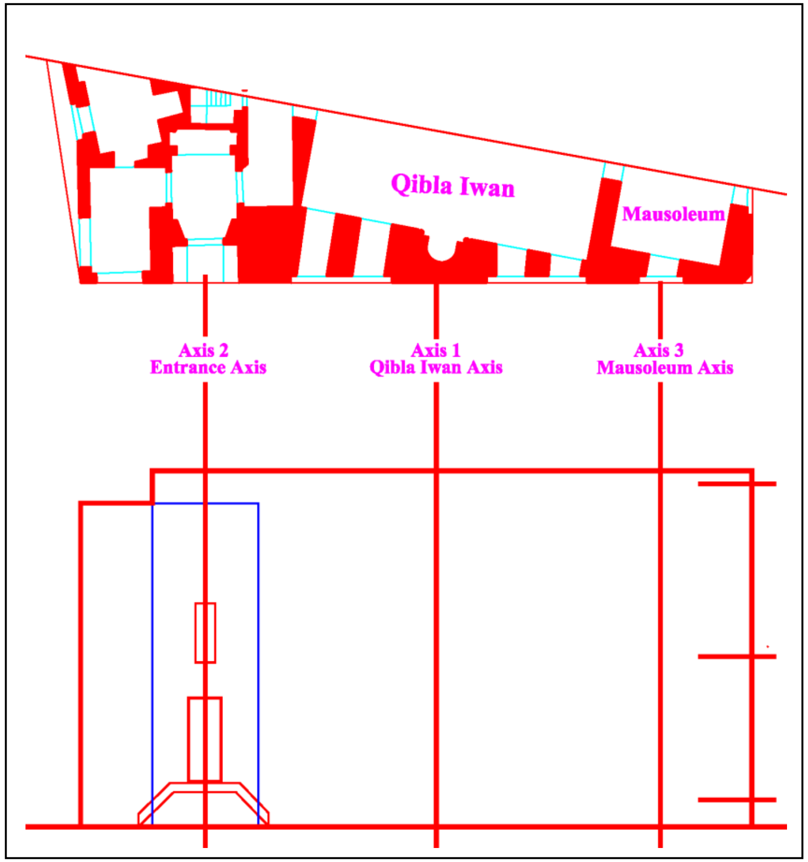
4- Add the sub-axes around the main axes



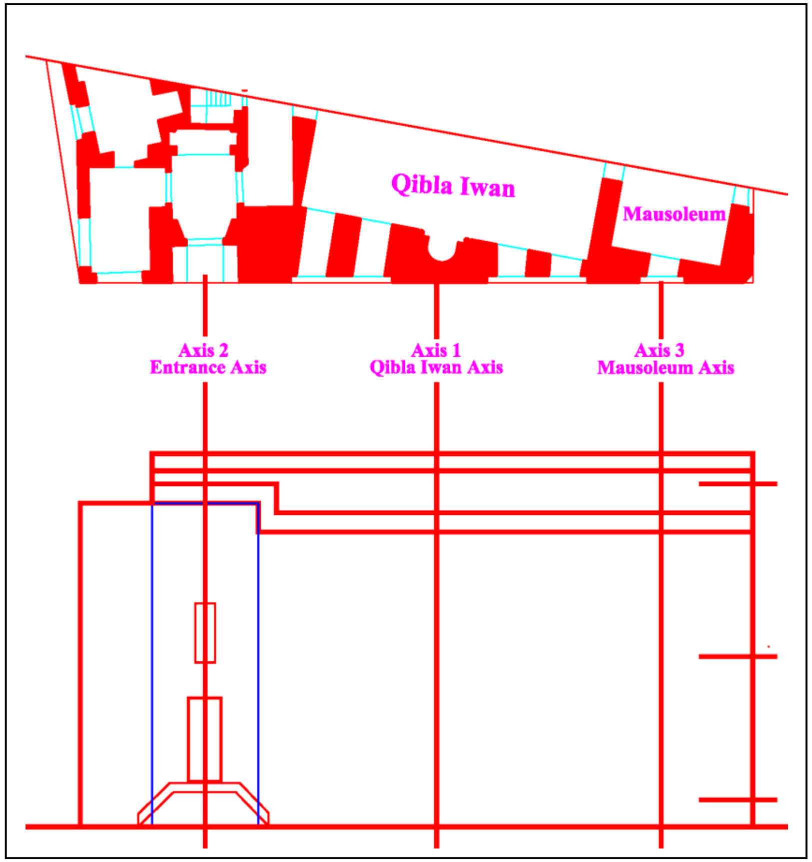
5- Determine the different floor levels



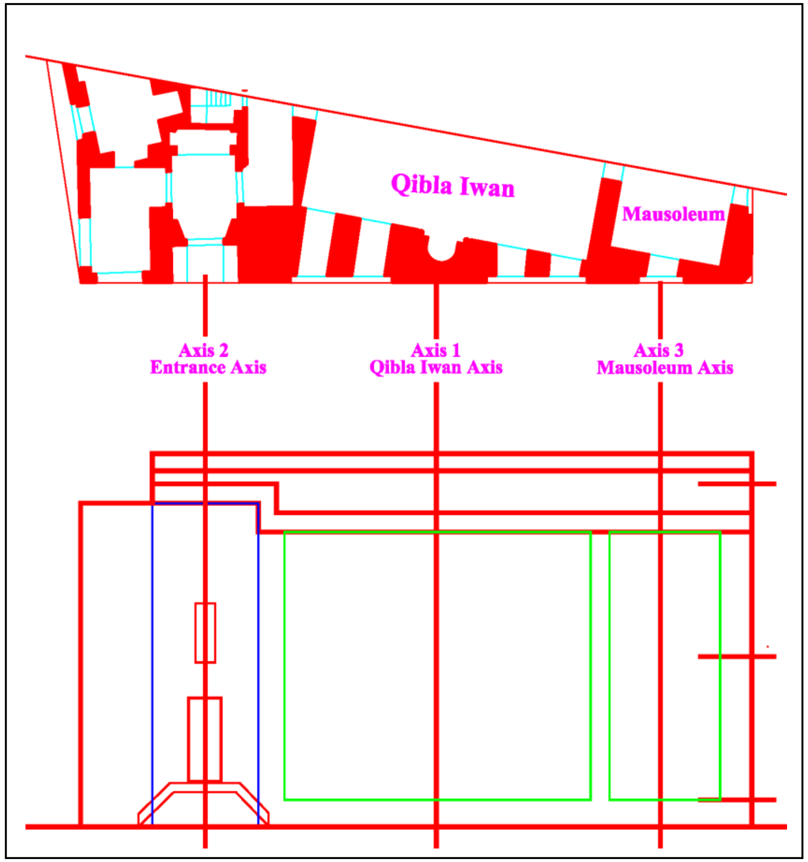
6- Add the entrance door and design the entrance panel



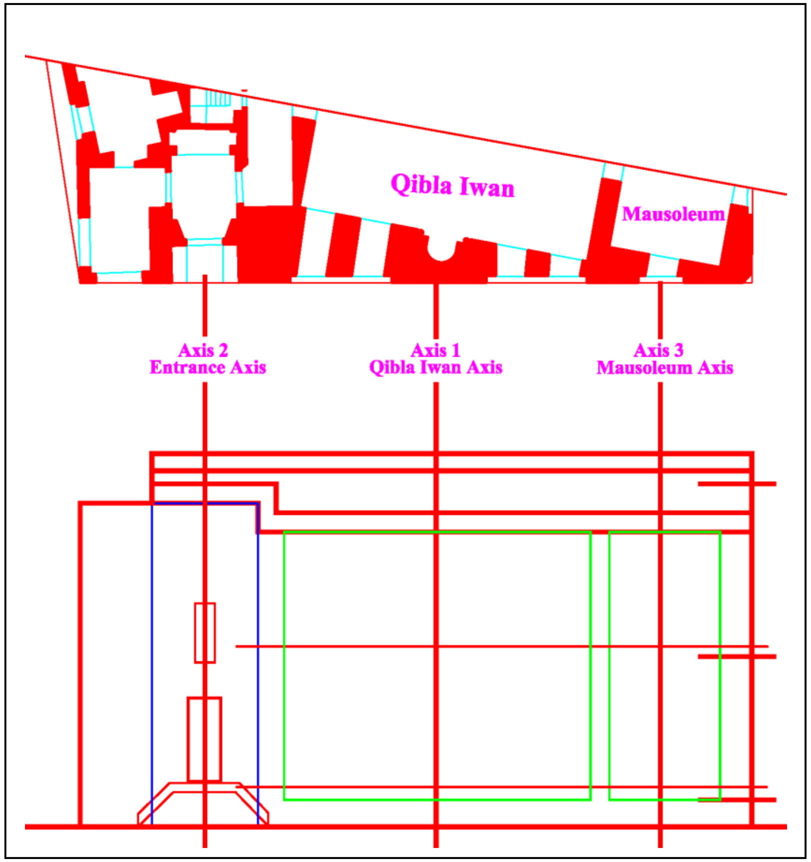
7- Determine the facade decoration elements position



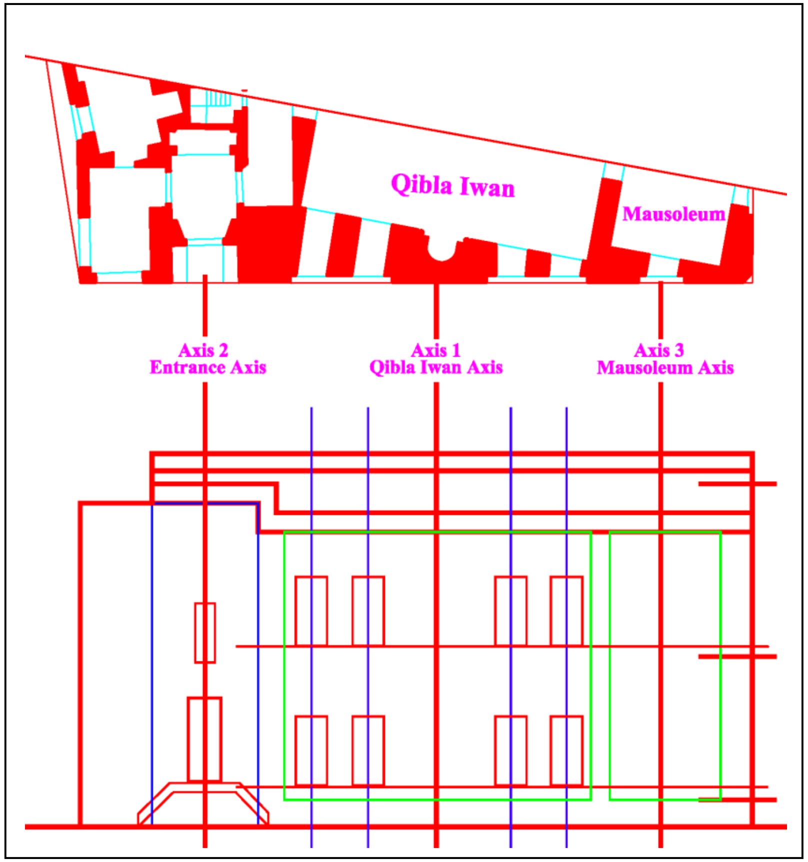
8- Add the facade's main squares



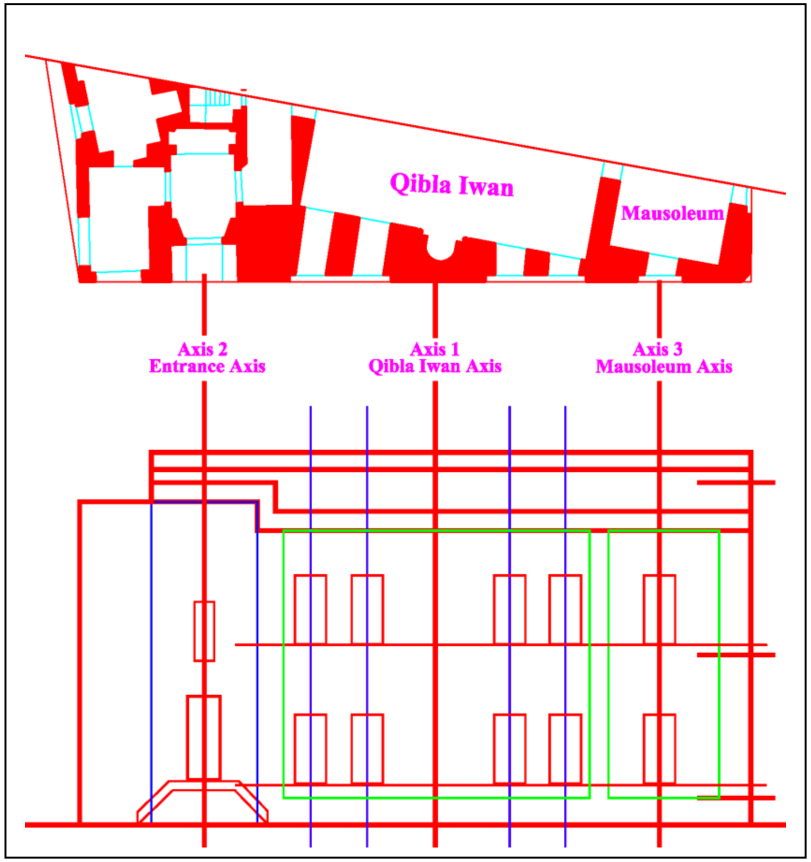
9- Determine the windows horizontal axes



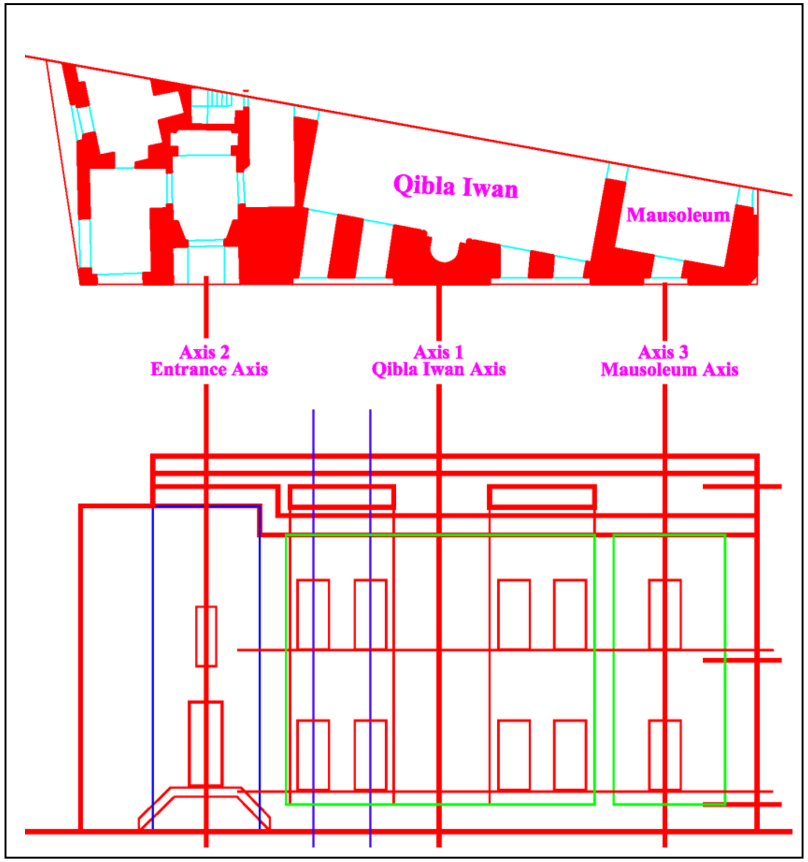
10- Identify the window's height on all levels



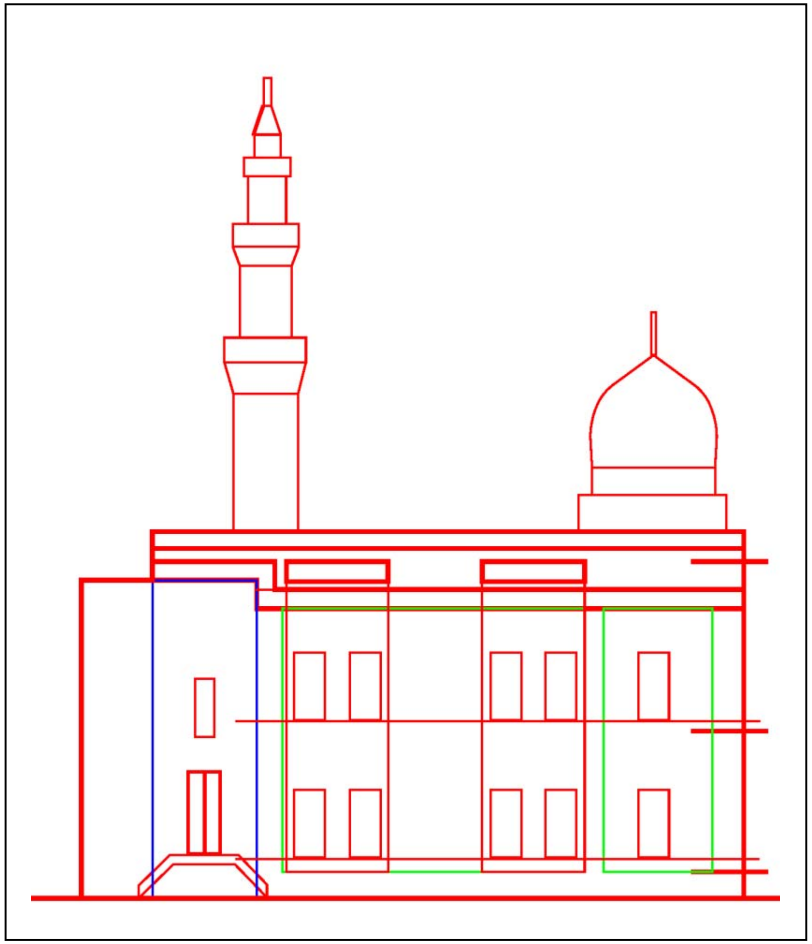
11- Complete the facade windows



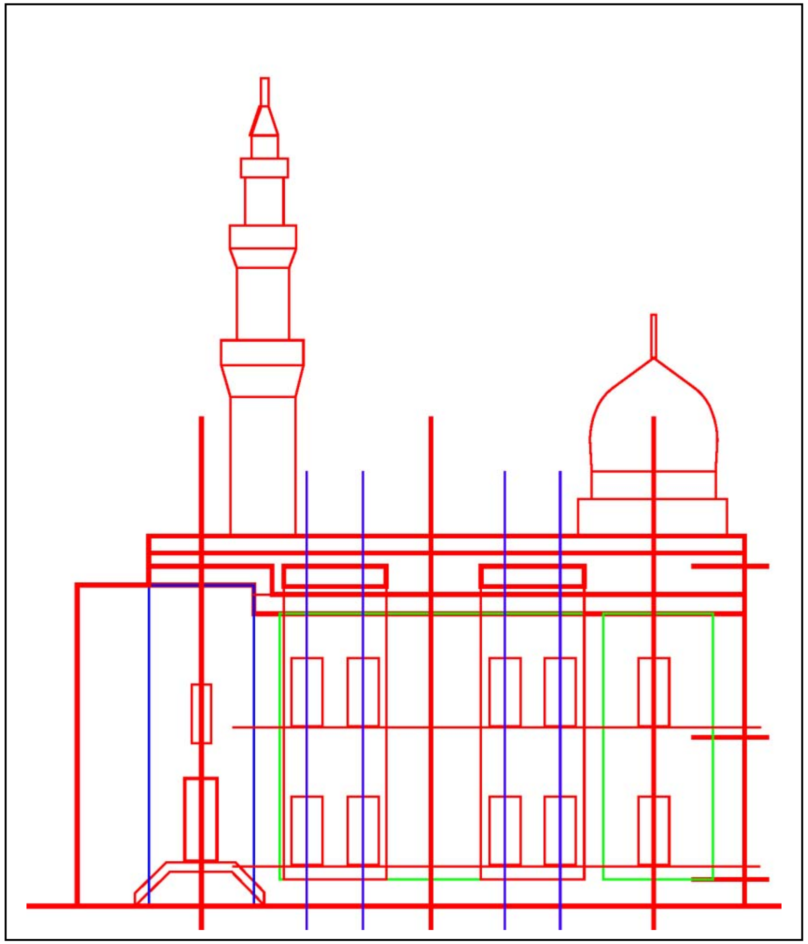
12- Add the facade decoration around the windows



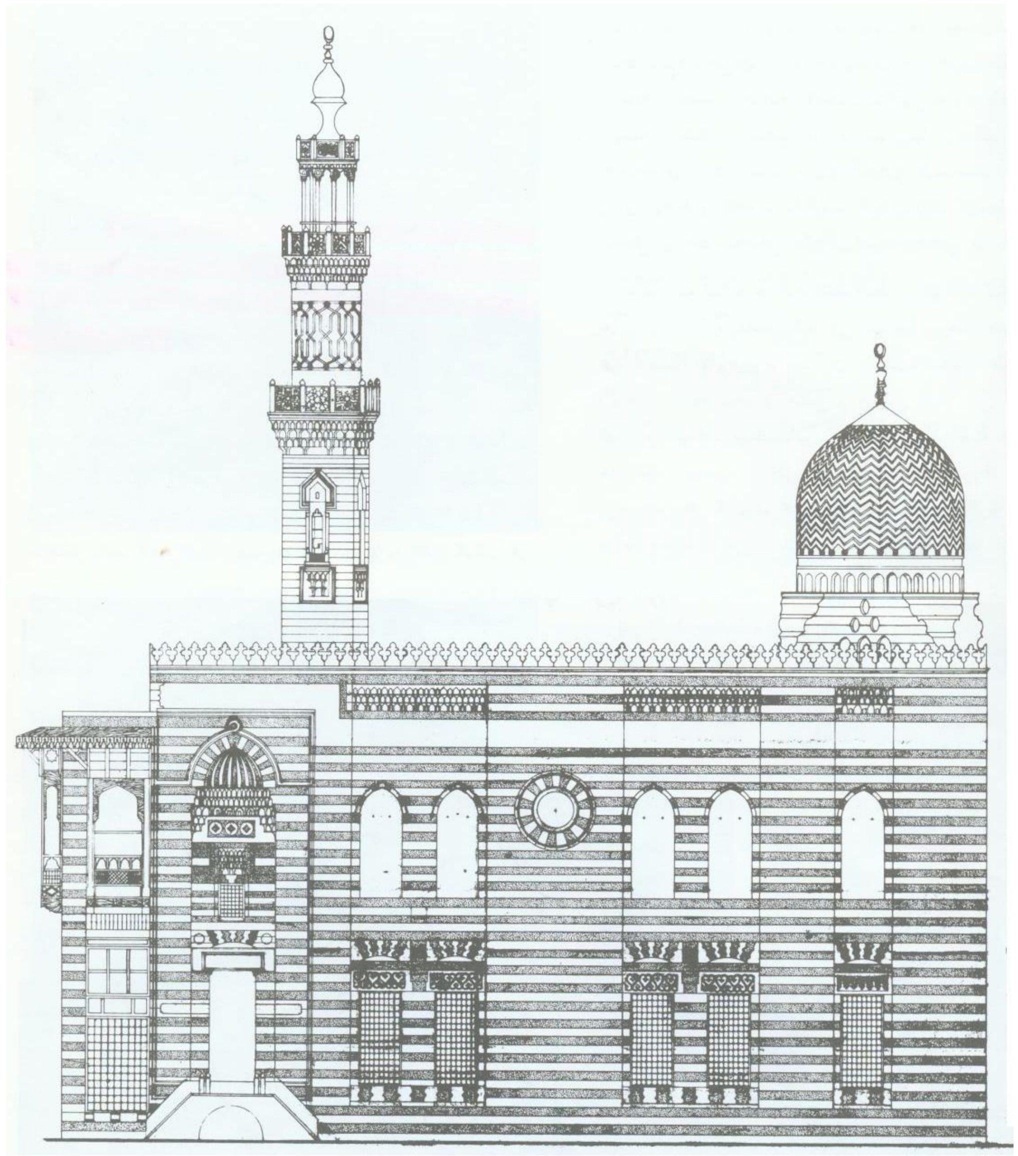
13- Complete the facade design (placing the minaret and the mausoleum's dome)



14- Make final Design of the facade with the hidden geometric order



15- Determine final shape of the facade

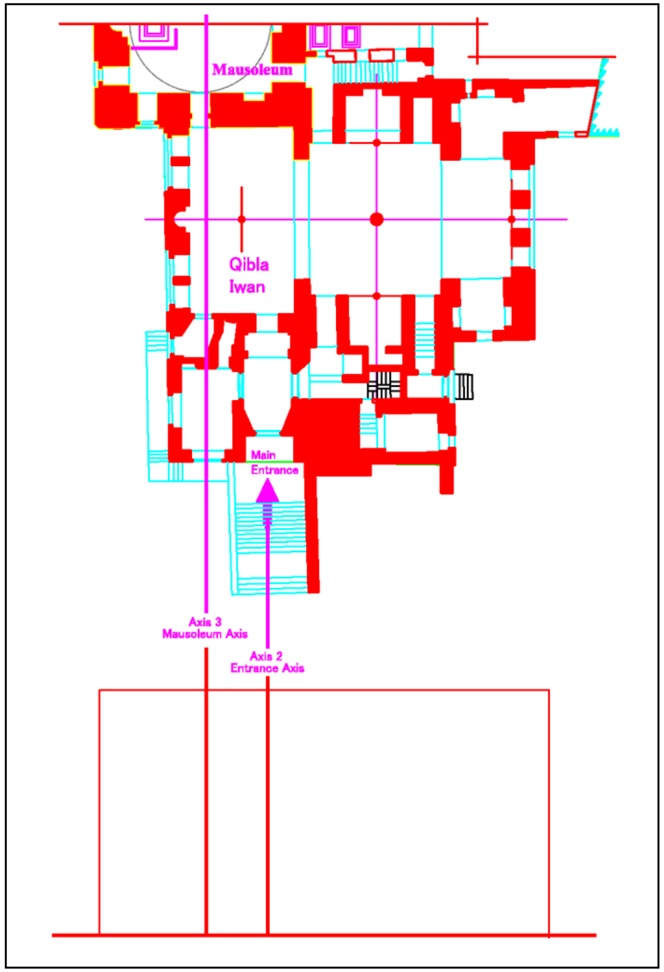


5.2.2.5 Madrasa of Sultan Qaytbay (1472-4 A.D.)

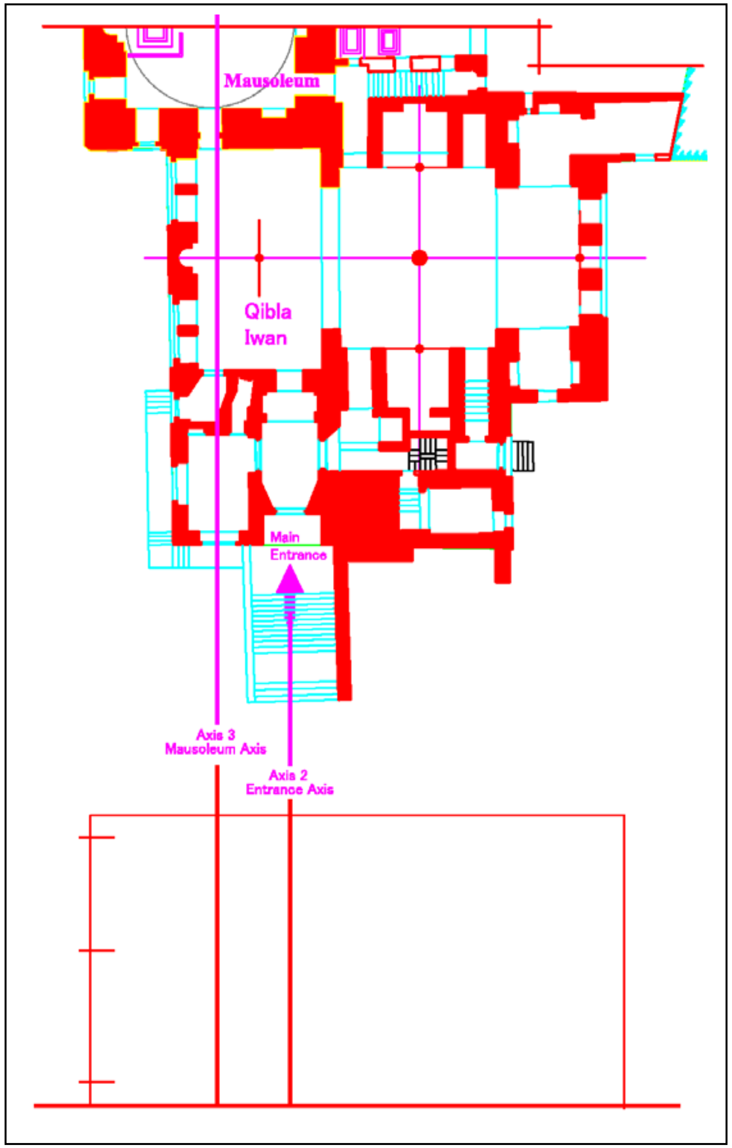
The geometric generative technique steps for generating facade design are applied in Madrasa of Sultan Qaytbay to show how the early Mamluk architect produced the building facade design according to a geometrical order control and motor his thinking. The steps are as follows:

1- Determine the facade boundary and its total height

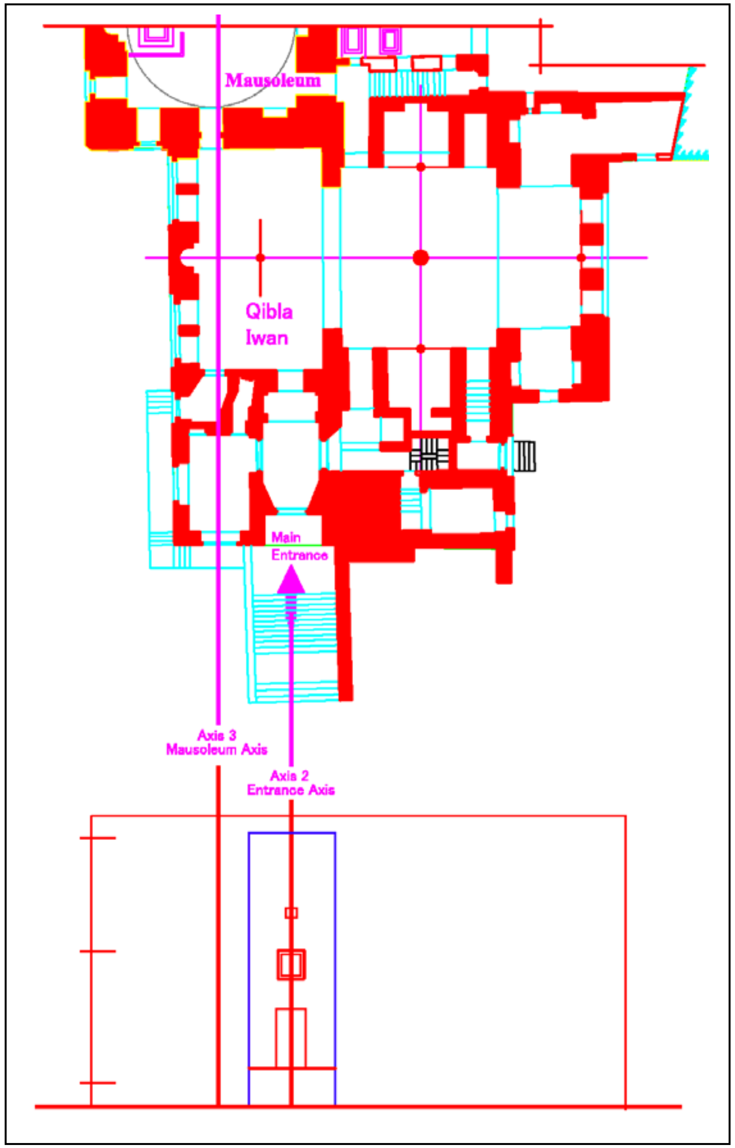
2- Add the main vertical axes of the facade



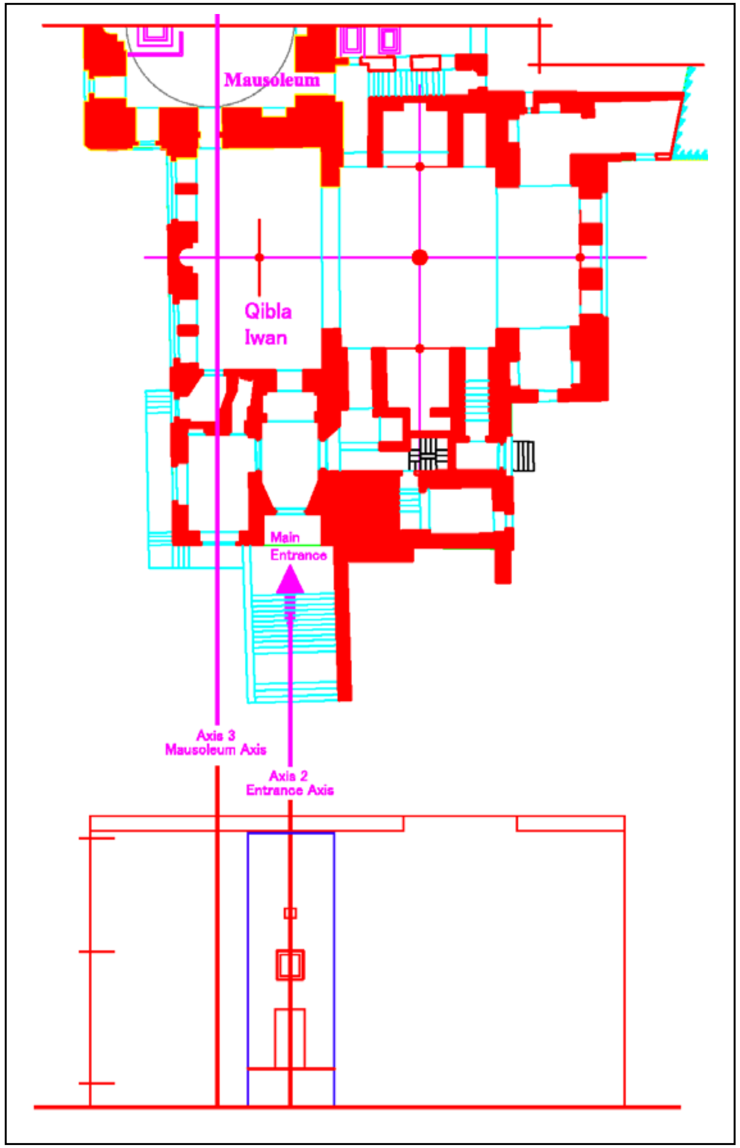
3- Determine the different floor levels



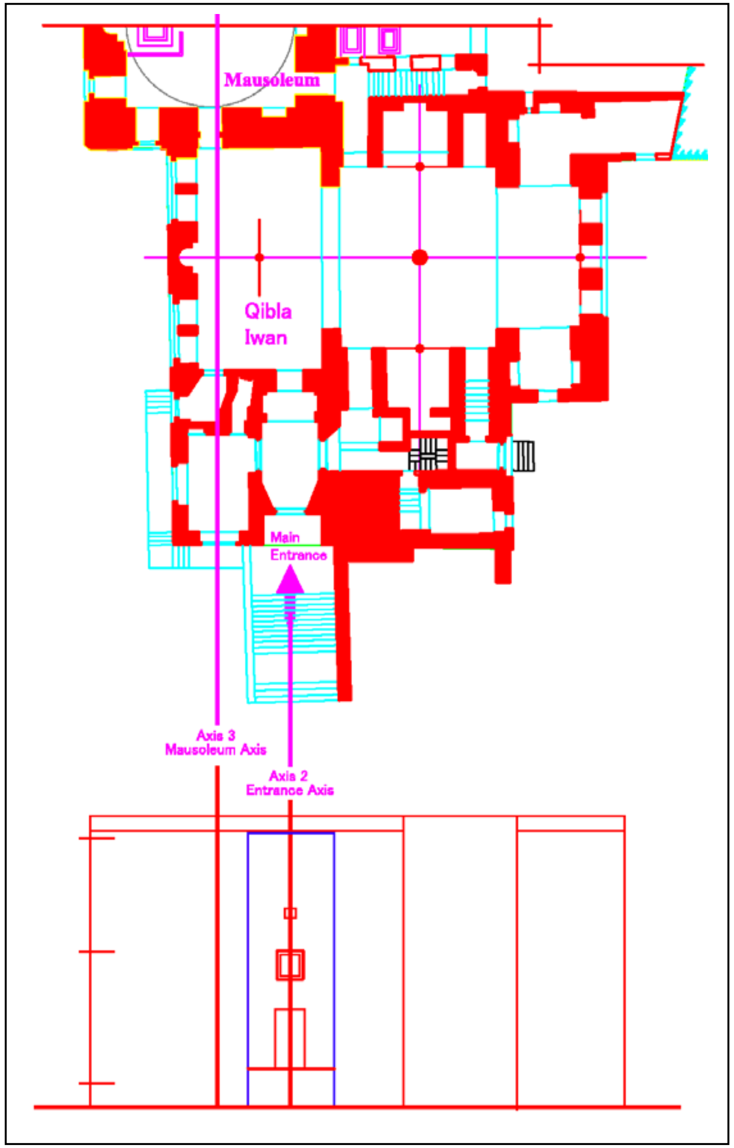
4- Add the entrance door and design the entrance panel



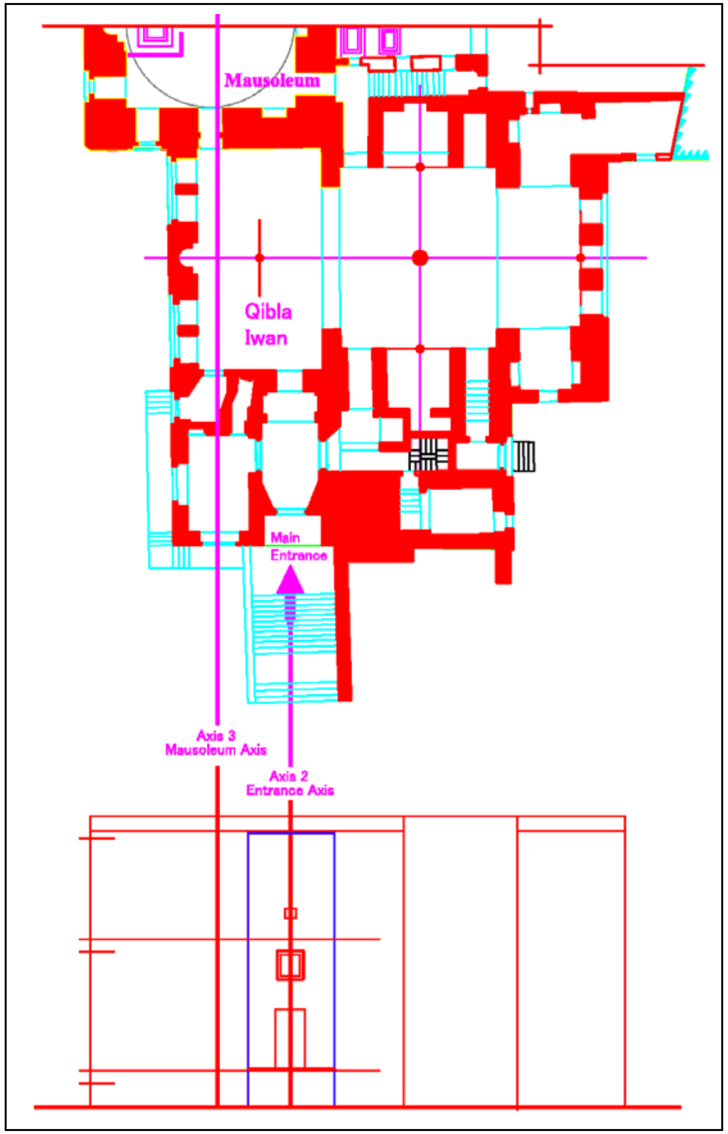
5- Determine the decoration elements position



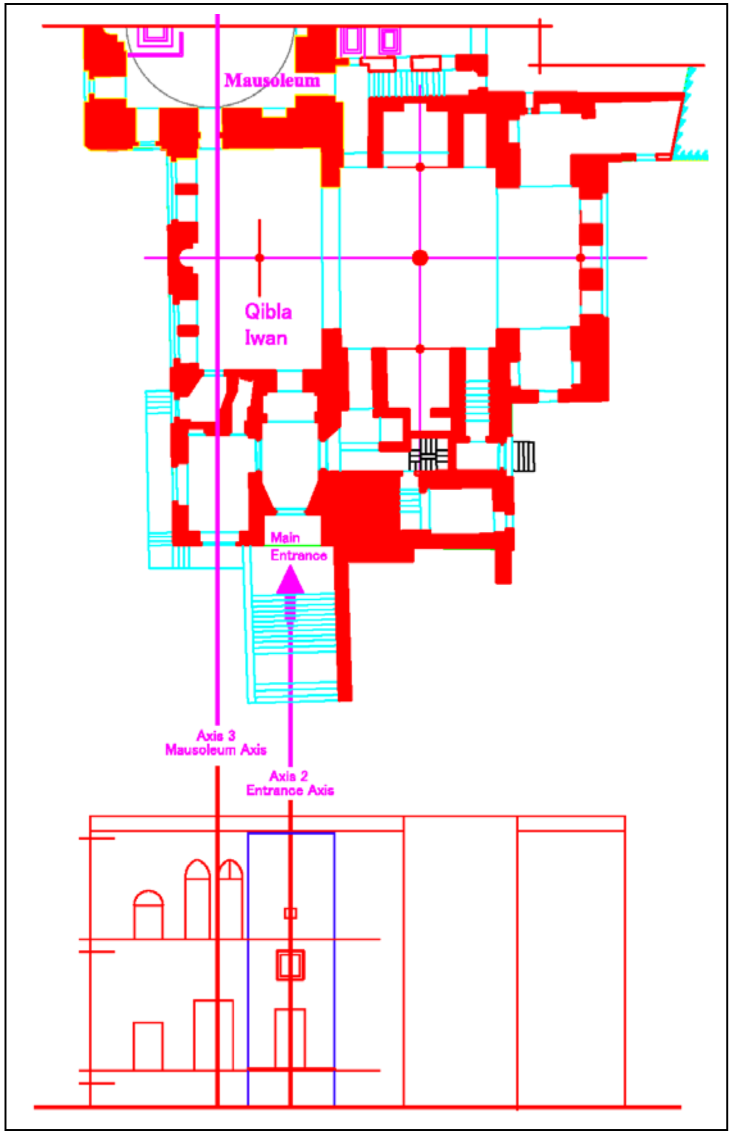
6- Add the facade's main squares



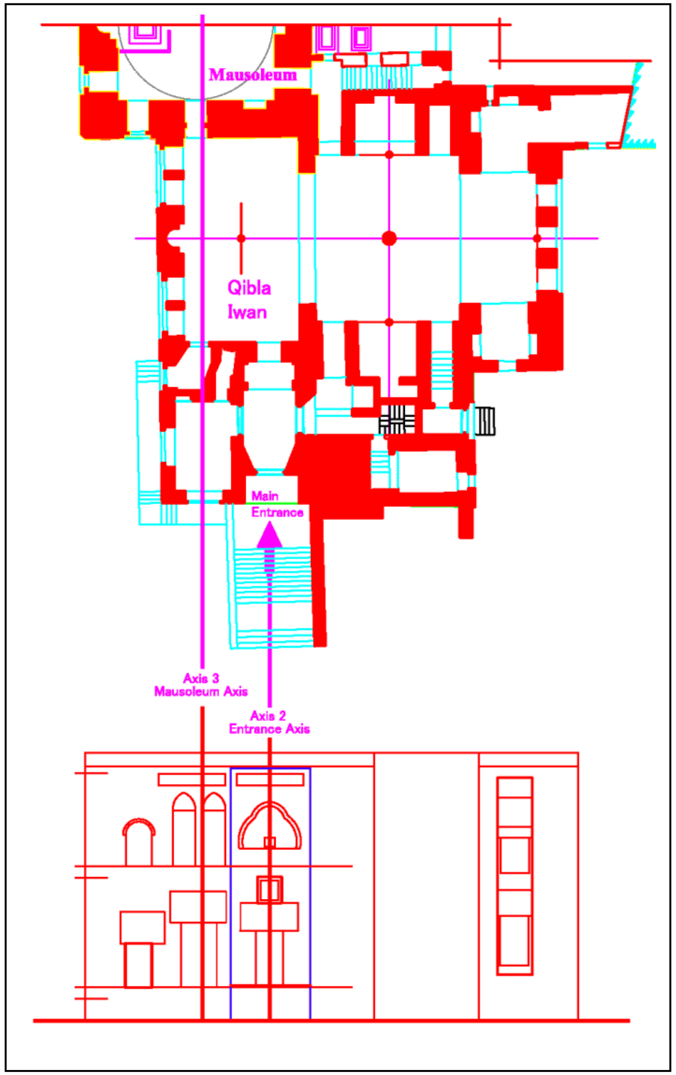
7- Determine the windows horizontal axes



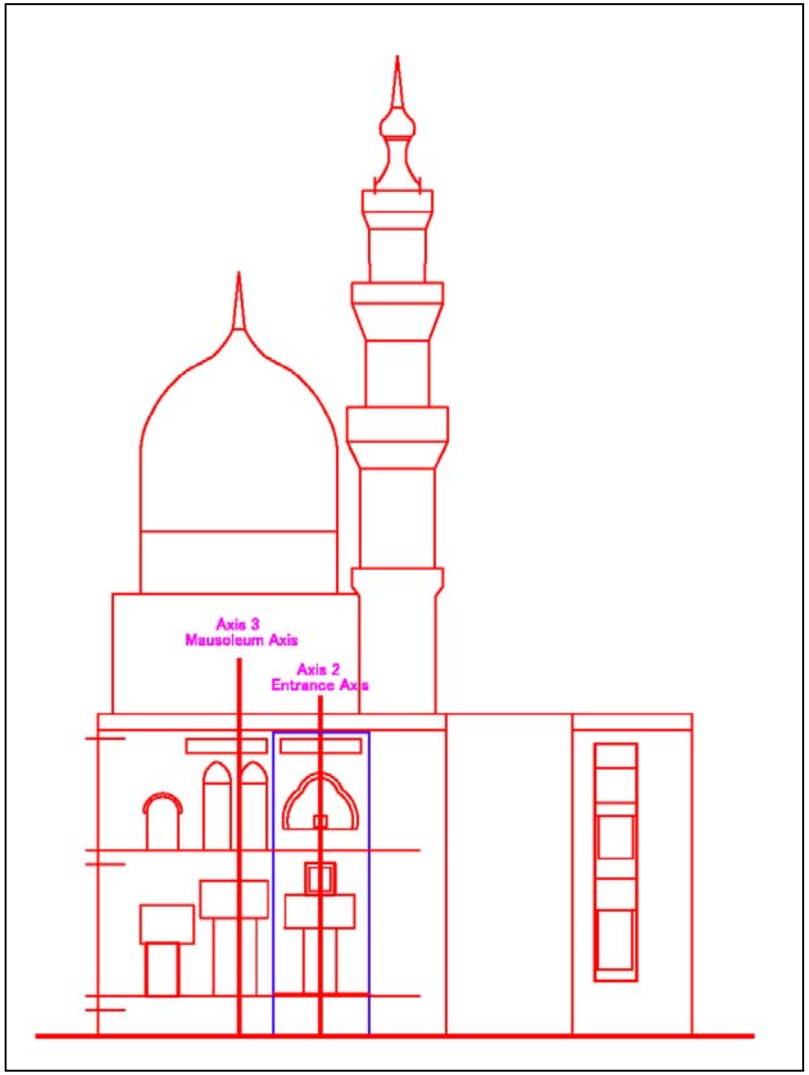
8- Identify the window's height in all levels



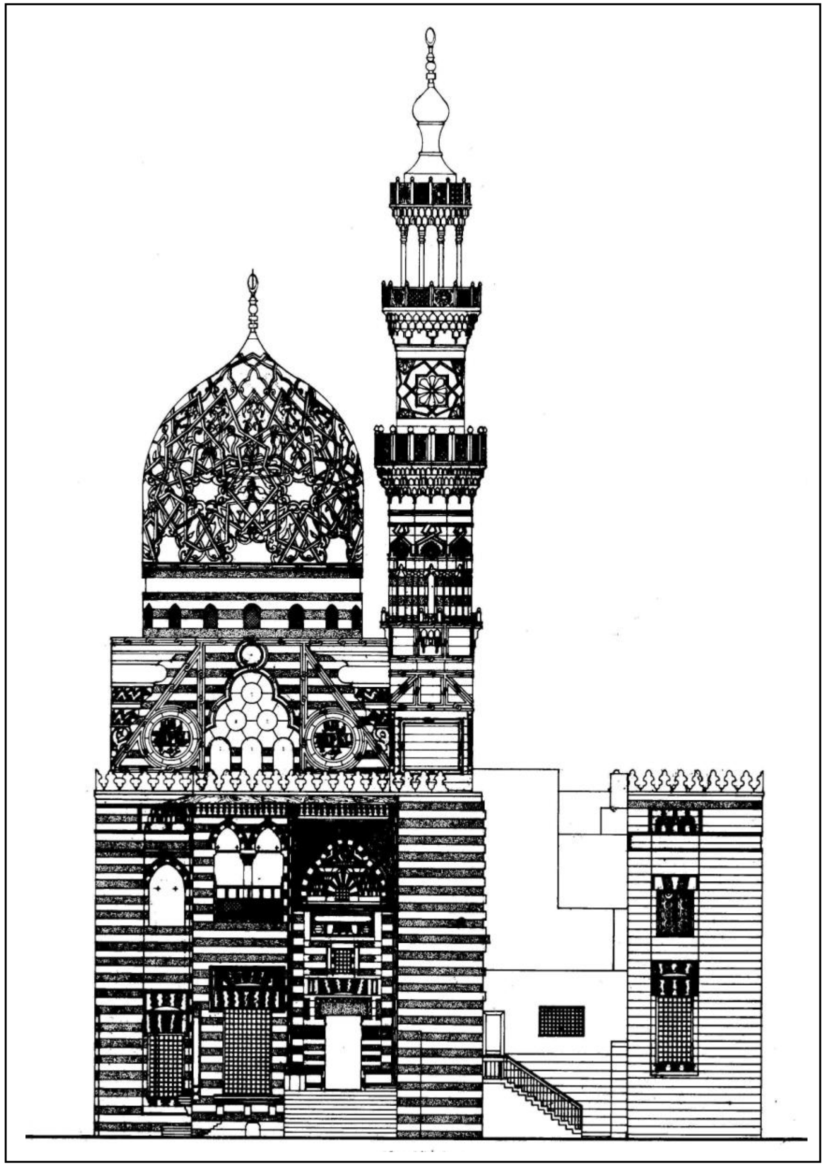
9- Complete the facade windows and locating the facade decoration around the windows



10- Complete the facade design (placing the minaret and the mausoleum's dome)



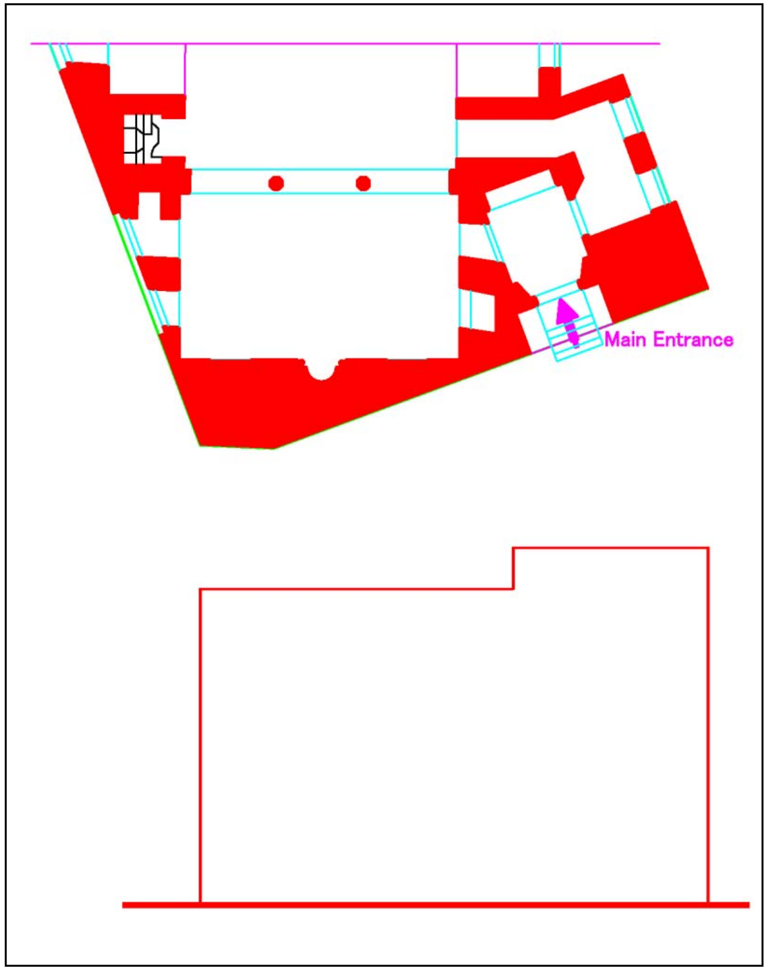
11- Determine final shape of the facade



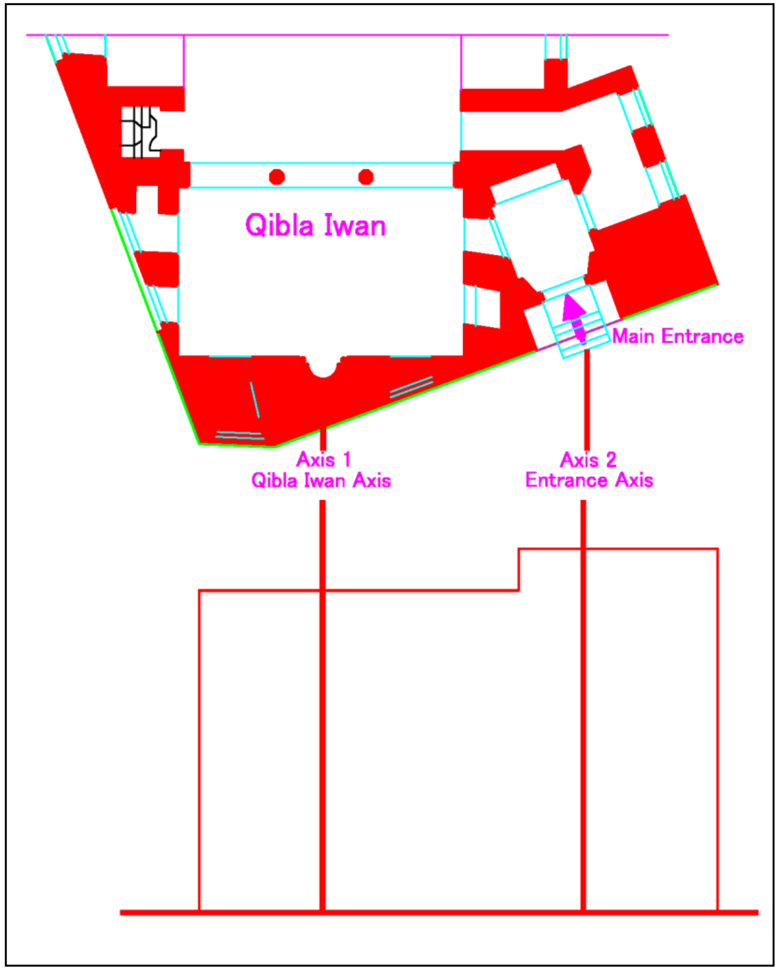
5.2.2.6 Madrasa of Qadi Abu Bakr Muzhir (1479-80 A.D.)

The geometric generative technique steps for generating façade design are applied in Madrasa of Qadi Abu Bakr Muzhir to show how the early Mamluk architect produced the building facade design according to a geometrical order control and motor his thinking. The steps are as follows:

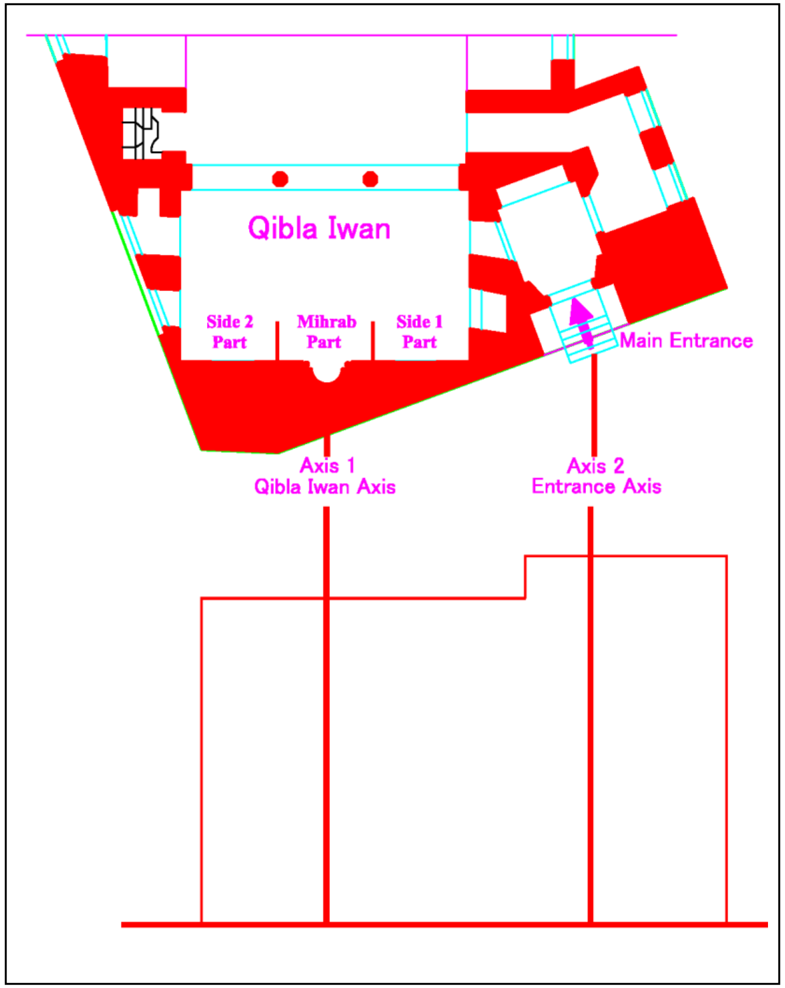
1- Determine the facade boundary and its total height



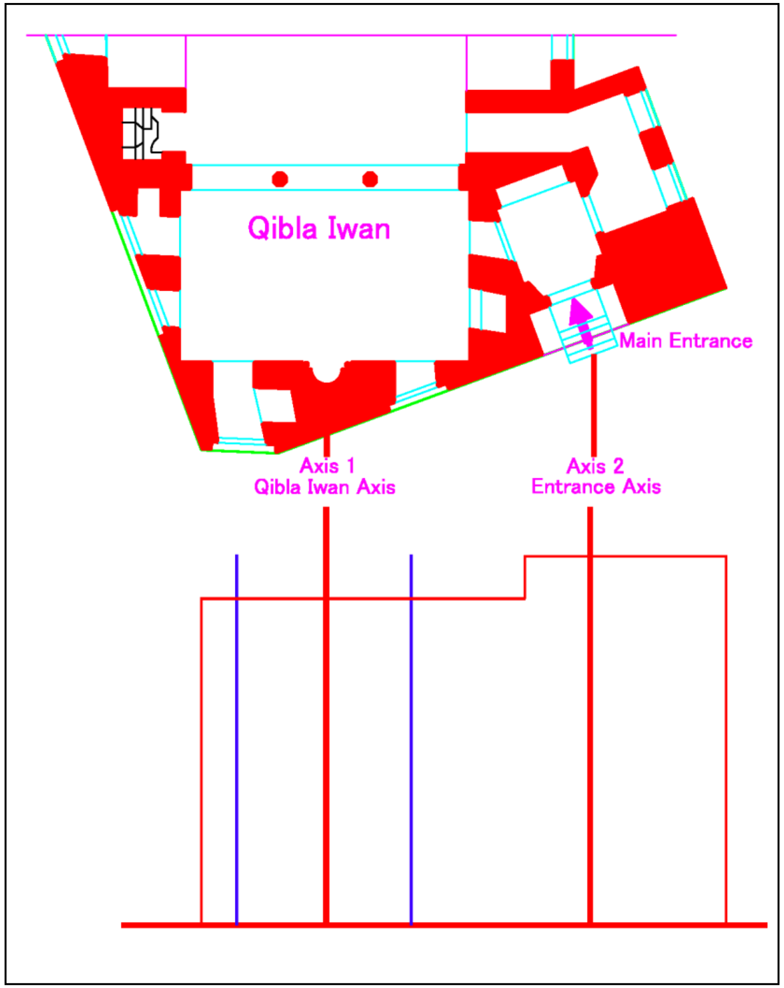
2- Add the main vertical axes of the facade



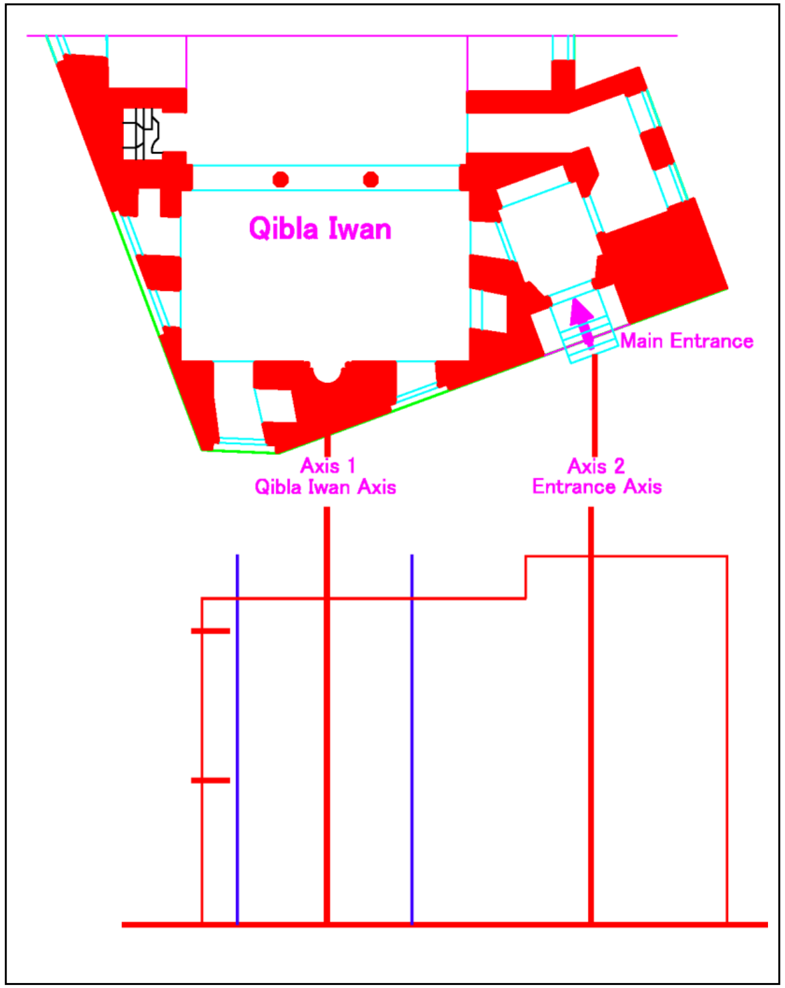
3- Divide the qibla wall into three major parts



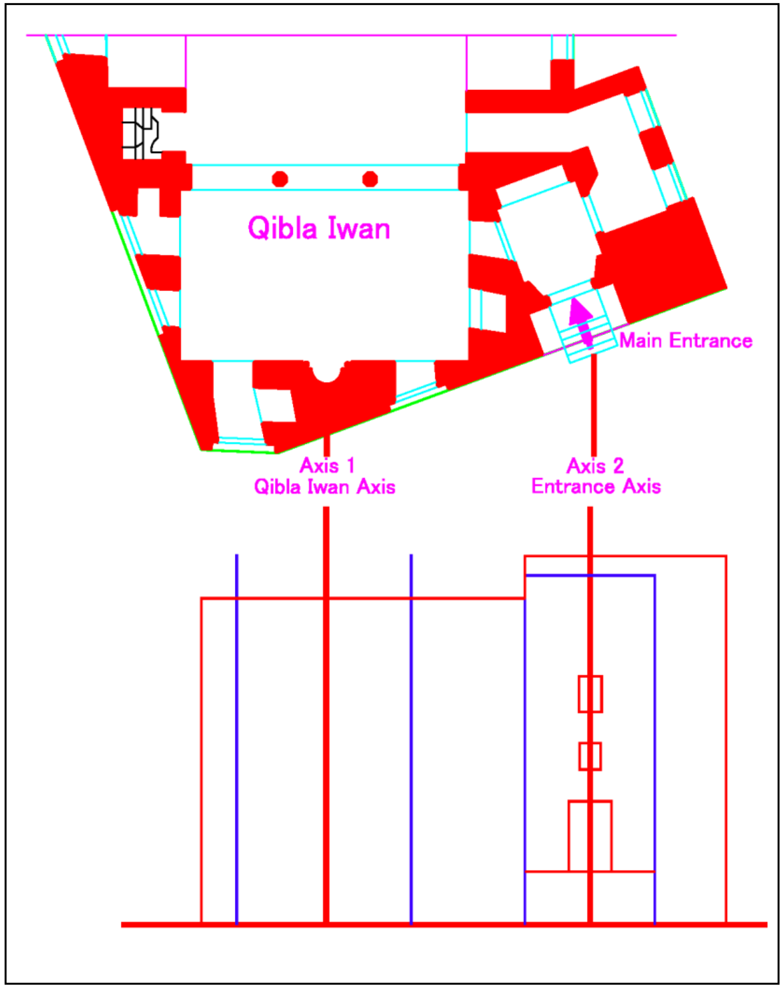
4- Add the sub-axes around the main axes



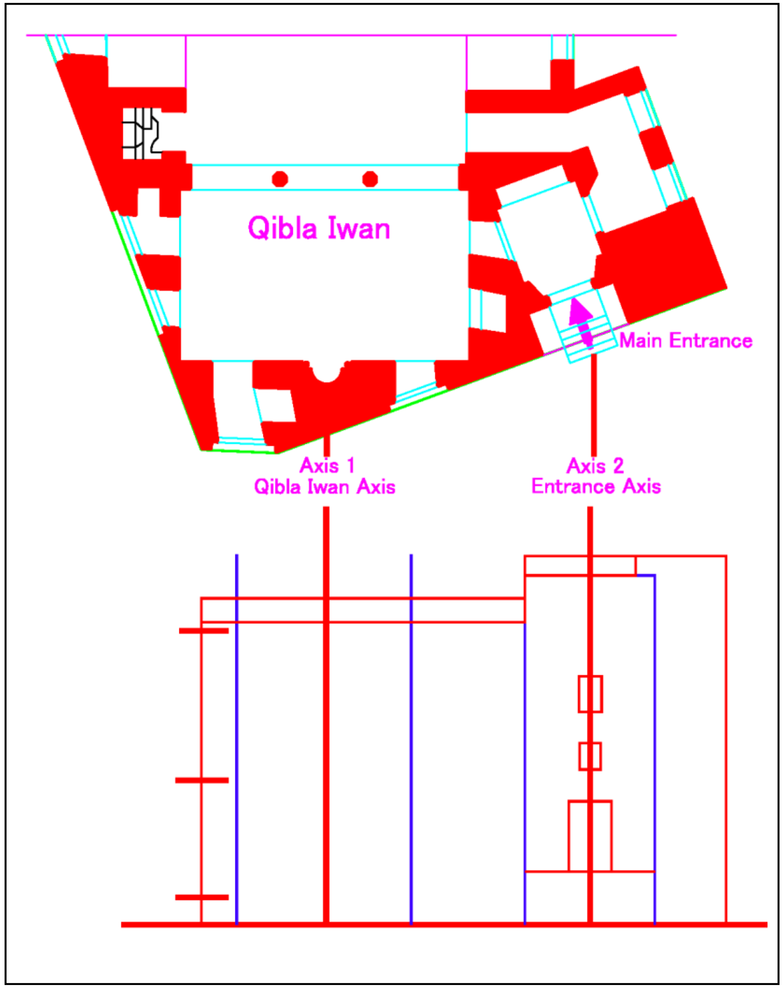
5- Determine the different floor levels



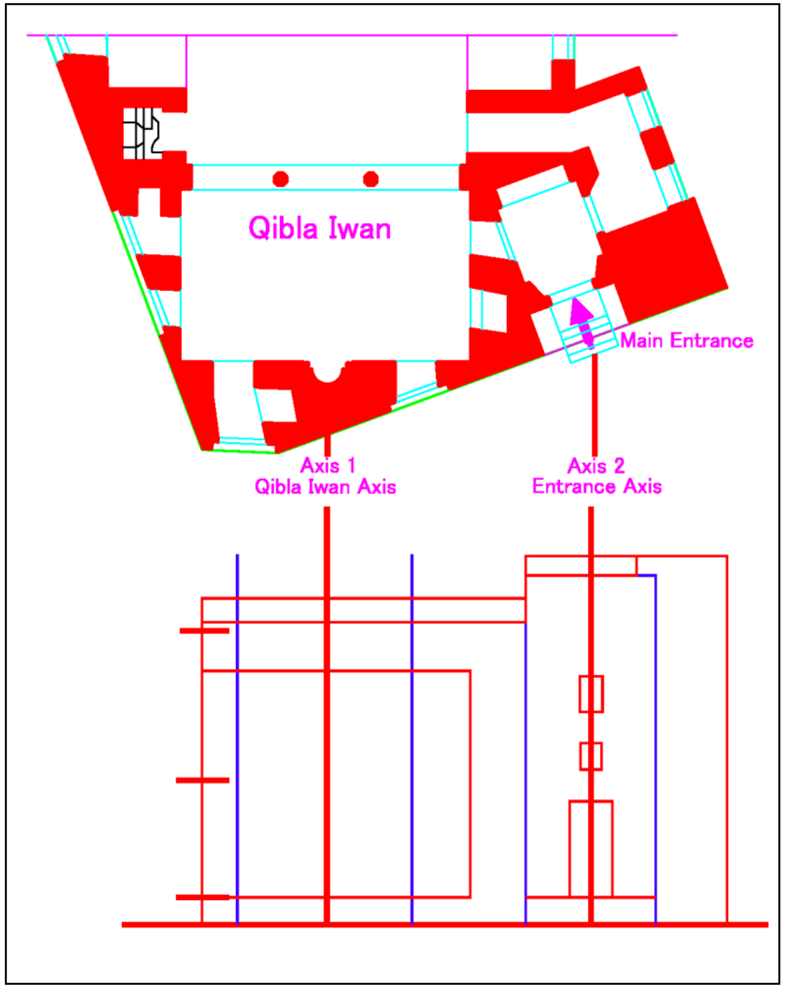
6- Add the entrance door and design the entrance panel



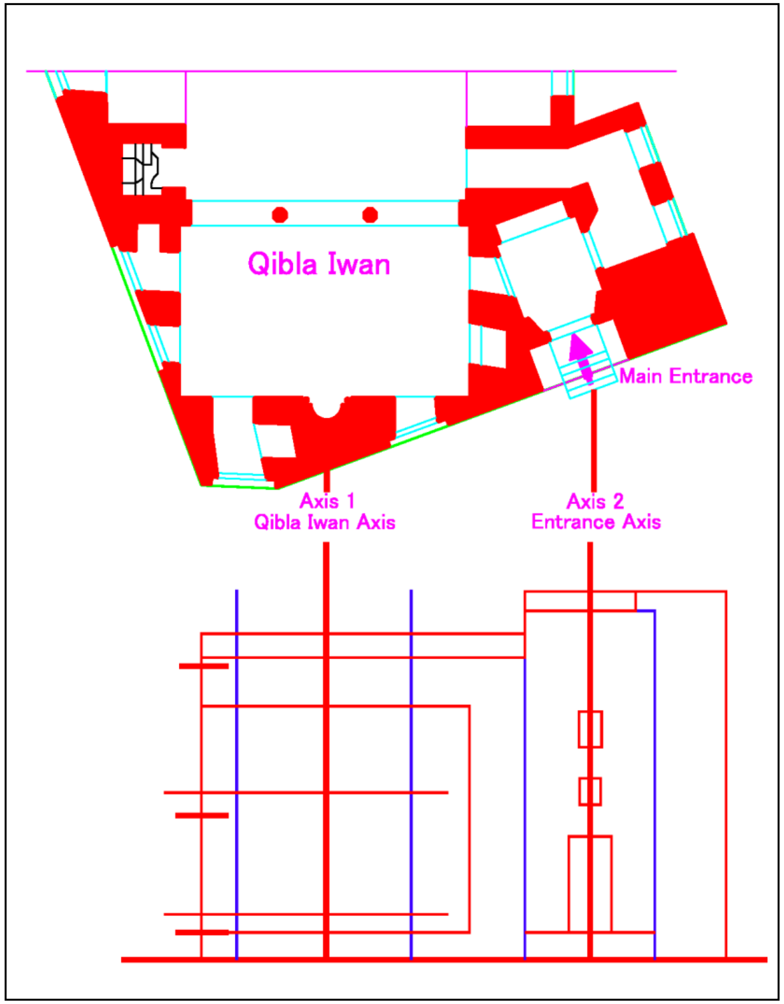
7- Determine the facade decoration elements position



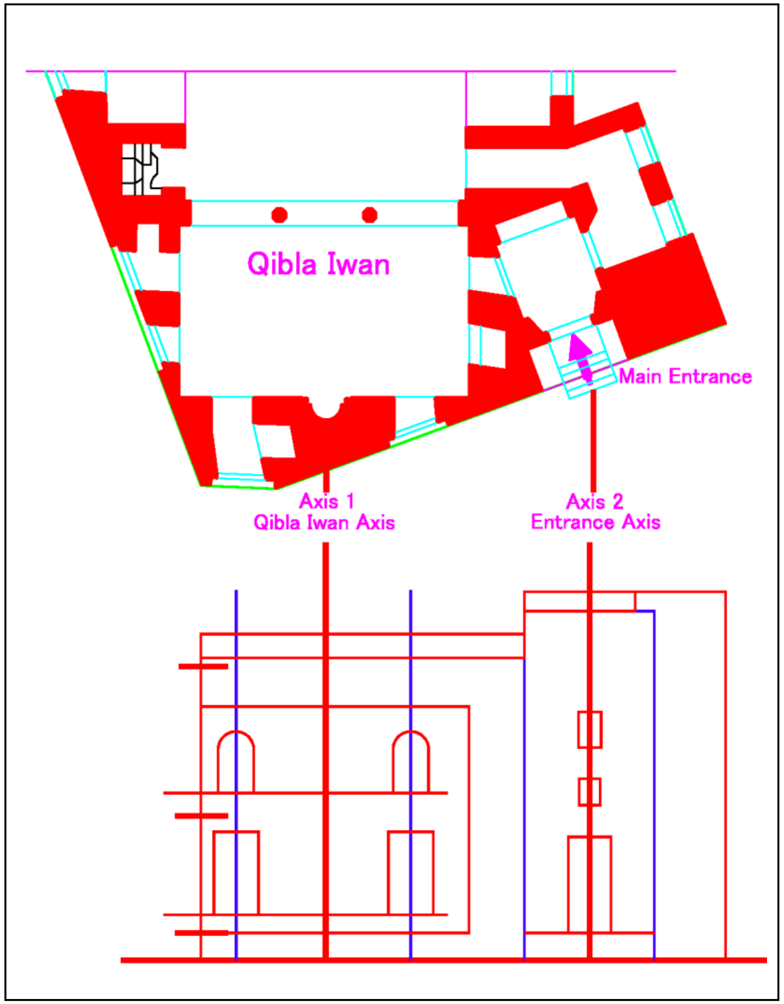
8- Add the facade's main squares



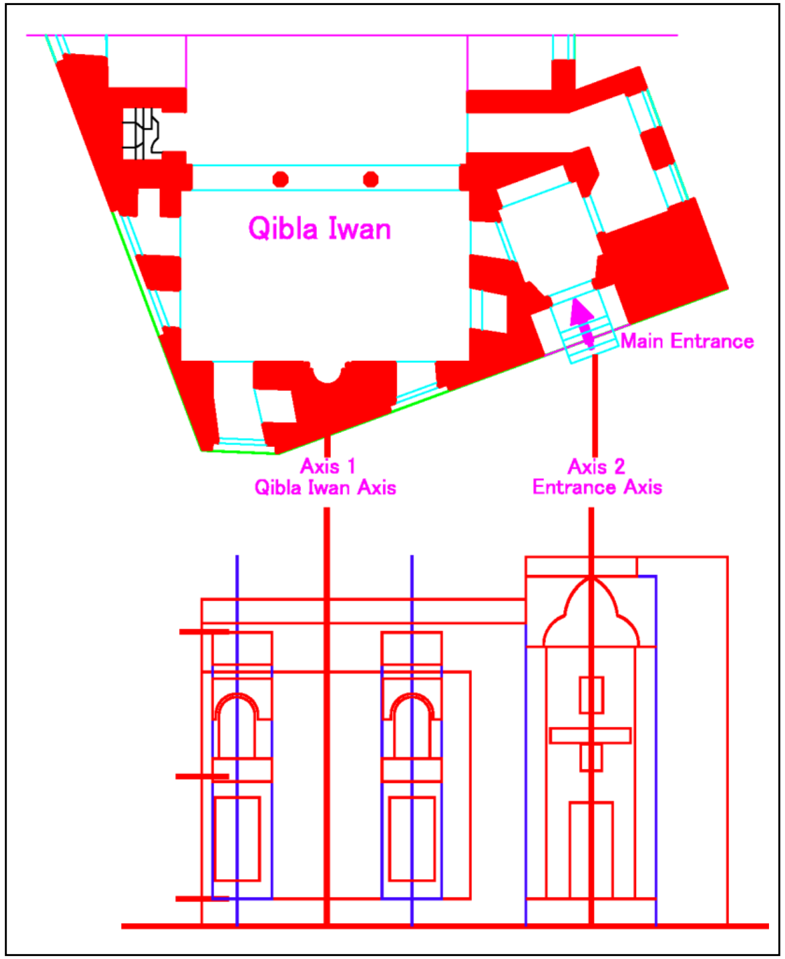
9- Determine the windows horizontal axes



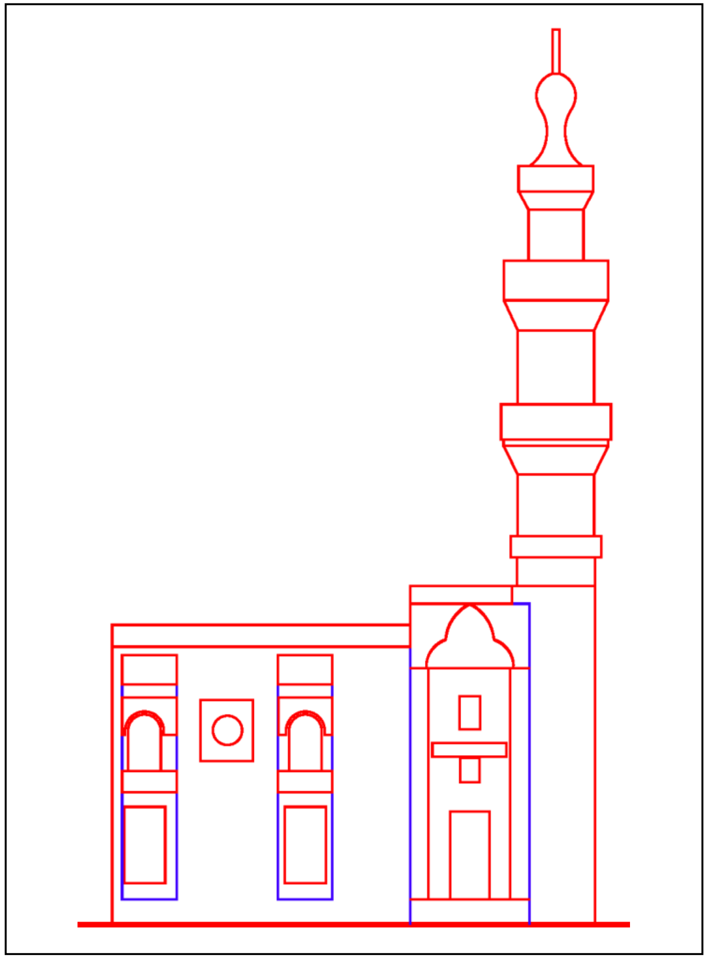
10- Identify the window's height in all levels



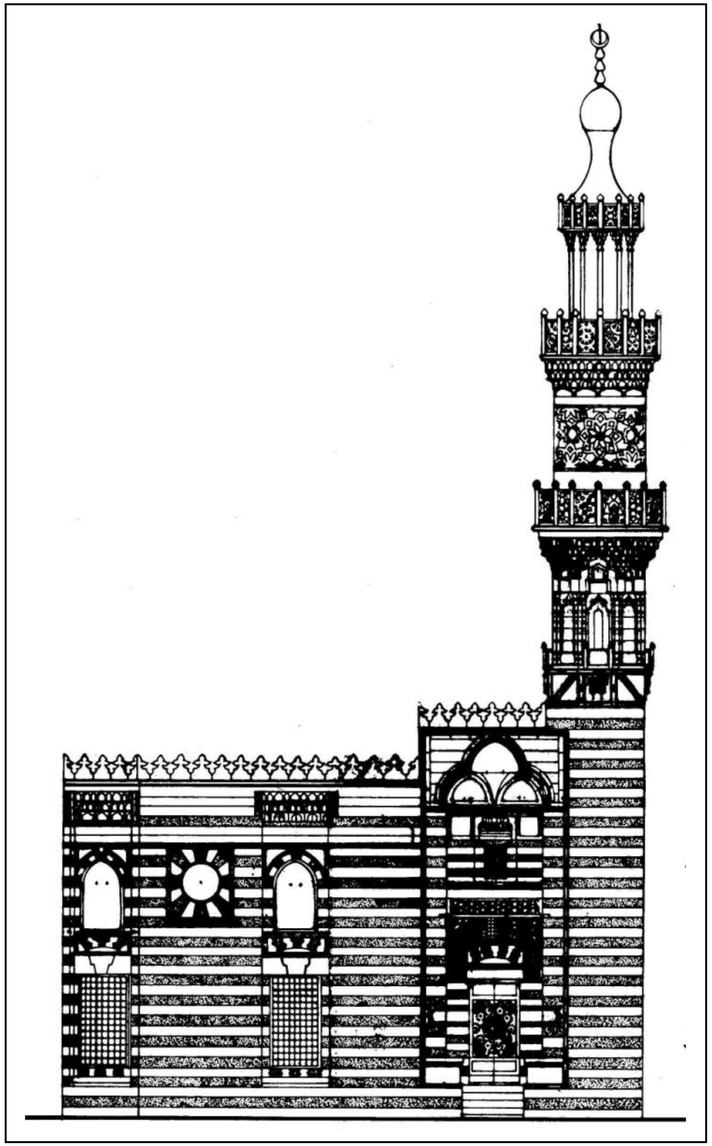
11- Add the facade decoration around the windows



12- Complete the facade design (locating the minaret)



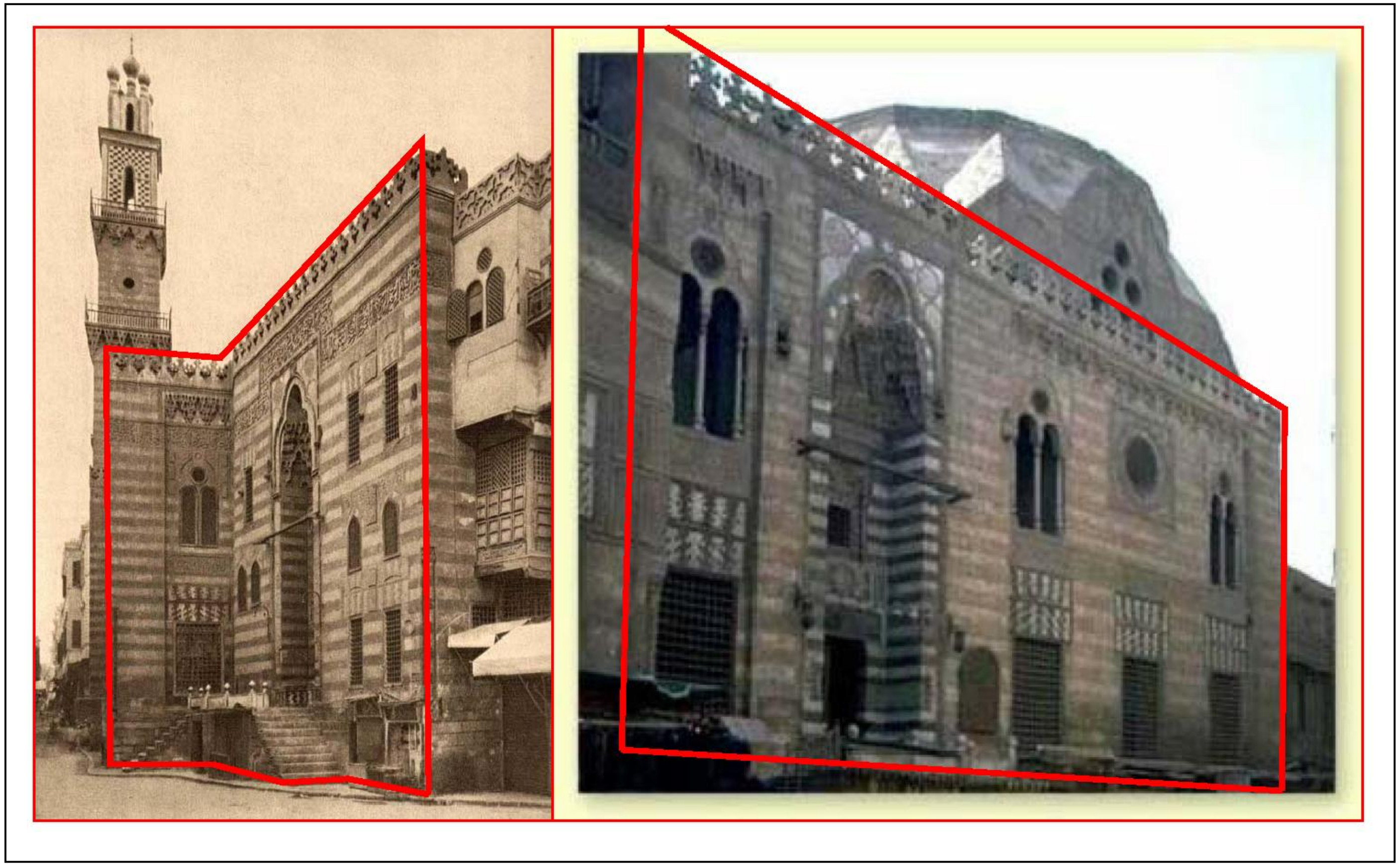
13- Determine final shape of the facade



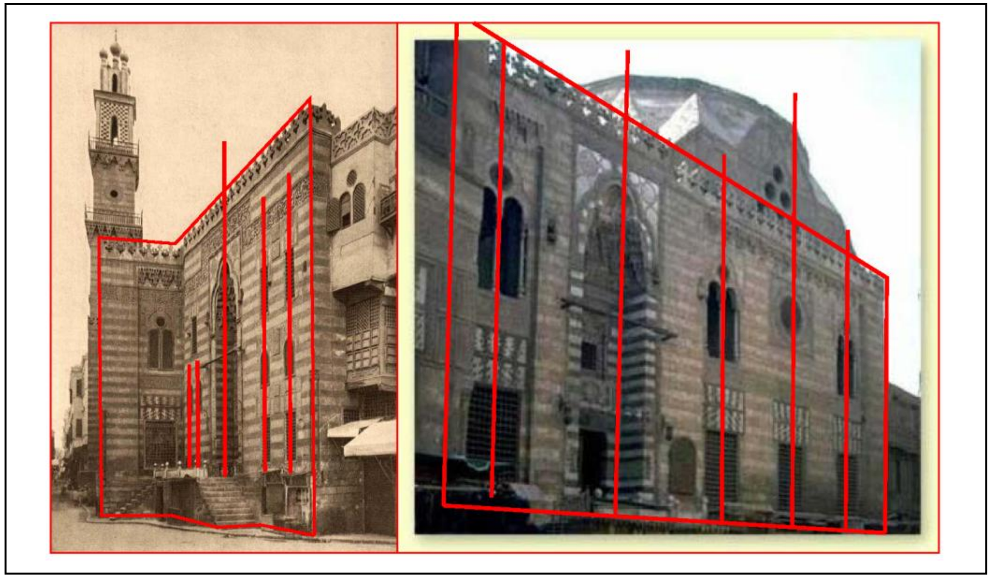
5.2.2.7 Madrasa of Sultan Qansuah al-Ghuri (1502-4 A.D.)

The geometric generative technique steps for generating façades design are applied in Madrasa of Sultan Qansuah al-Ghuri to show how the early Mamluk architect produced the building facade design according to a geometrical order control and motor his thinking. The steps are as follows:

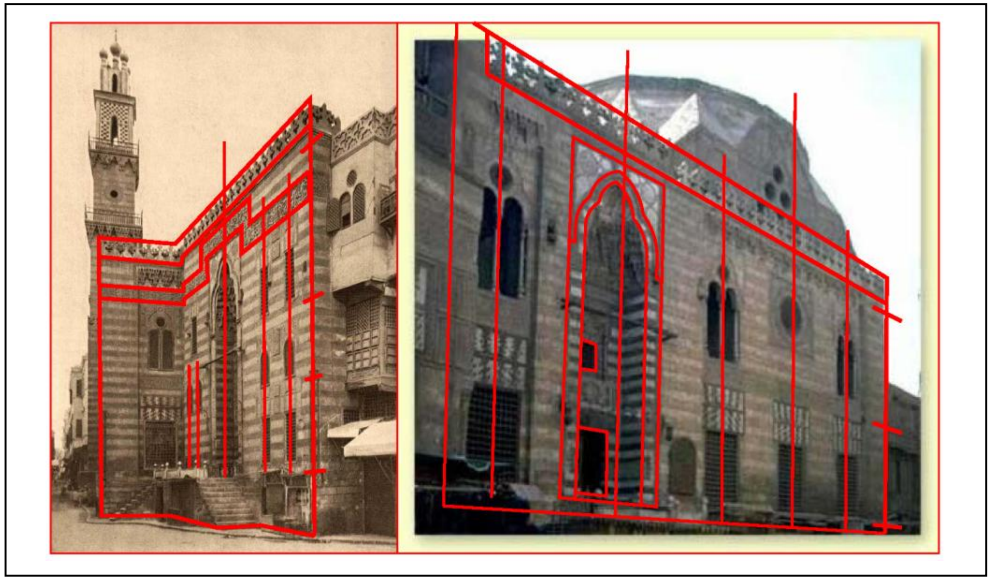
1- Determine the facade boundary and its total height.



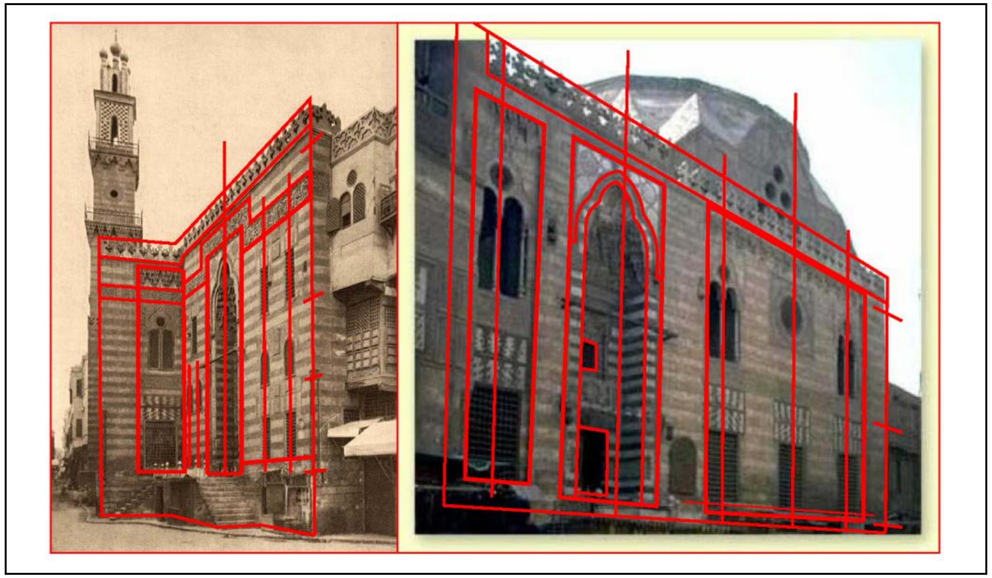
2- Add the main vertical axes of the facade and the sub-axes around the main axes.



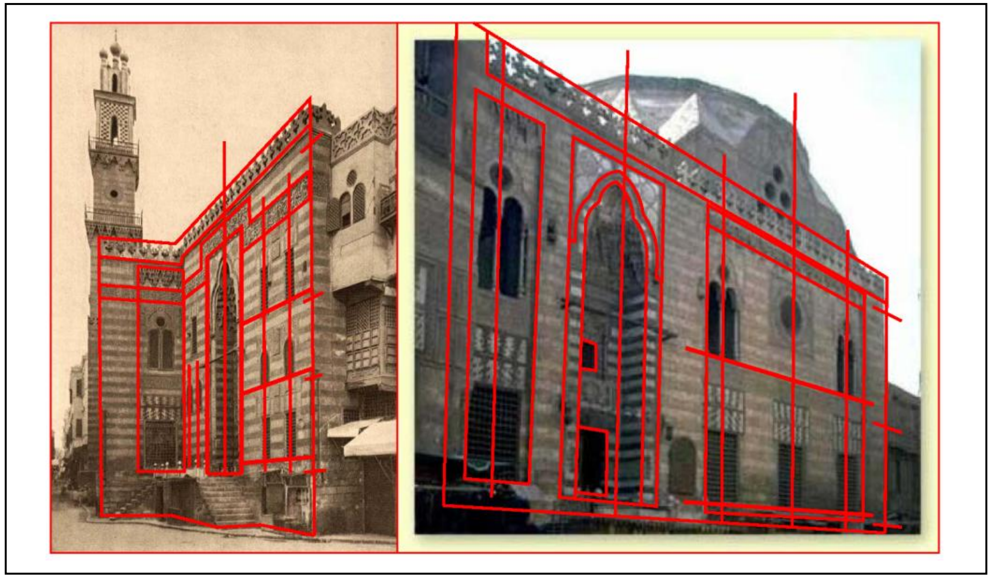
3- Determine the different floor levels, design the entrance panel and determine the decoration elements position.



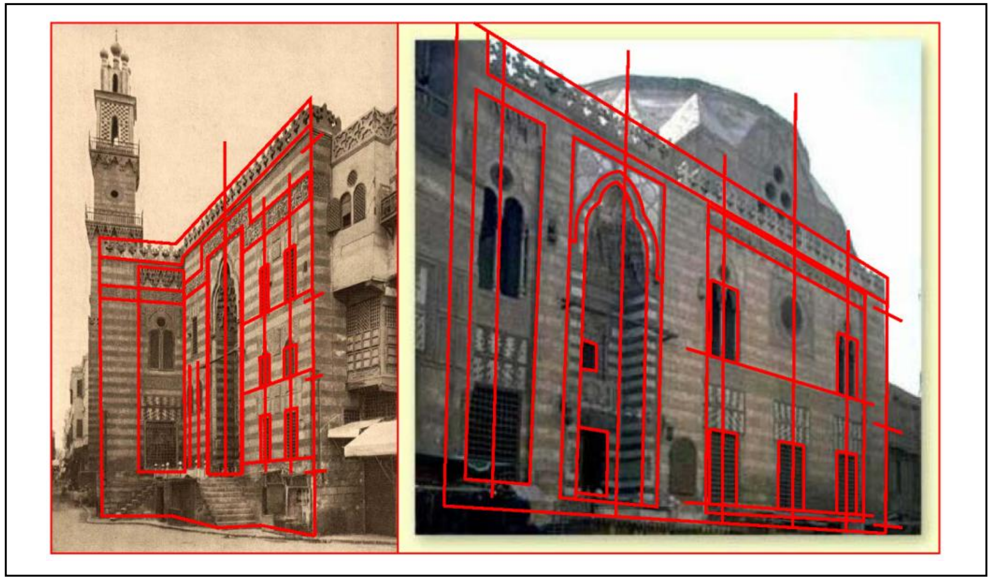
4- Add the facade's main squares.



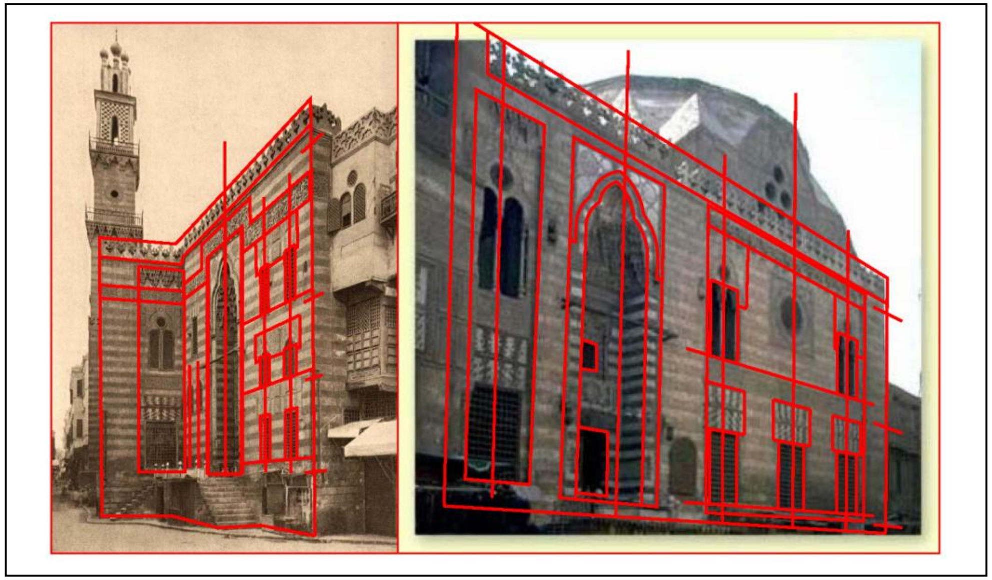
5- Determine the windows horizontal axes.



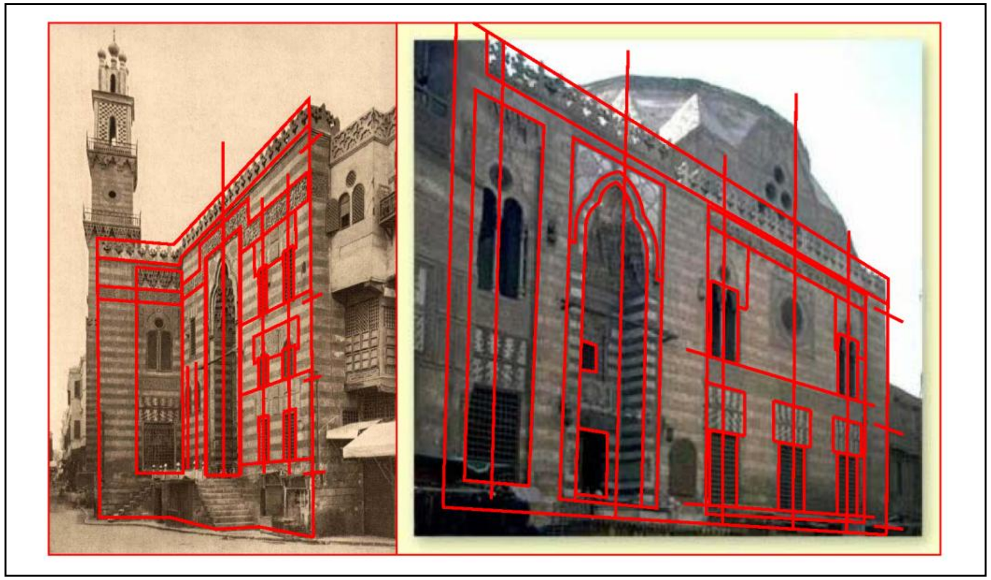
6- Identify the window's height in all levels and complete all the facade windows.



7- Add the facade decoration around the windows.



8- Make final design of the facade with the hidden geometric order.



9- Determine final shape of the facade.

5.3. Conclusion

From applying the geometric generative technique to the case-study buildings, four main results can be obtained:

- The design of madrasa buildings in Mamluk architecture depends mainly on geometric order, not only on the building space design but also on the building facade design as well as the building's inside and outside decoration.
- The science of geometry in the Mamluk era was very sophisticated and reflected in a very clear vision in the architecture and especially in madrasa buildings design.
- The relationship between the building and its urban context is a very important factor affecting the building's design.
- There is a determined space composition system which governing the space design process in the madrasa building.

From applying the geometric generative technique to the case-study buildings, the philosophy frame of the Mamluk designer can be expressed in the following figure.

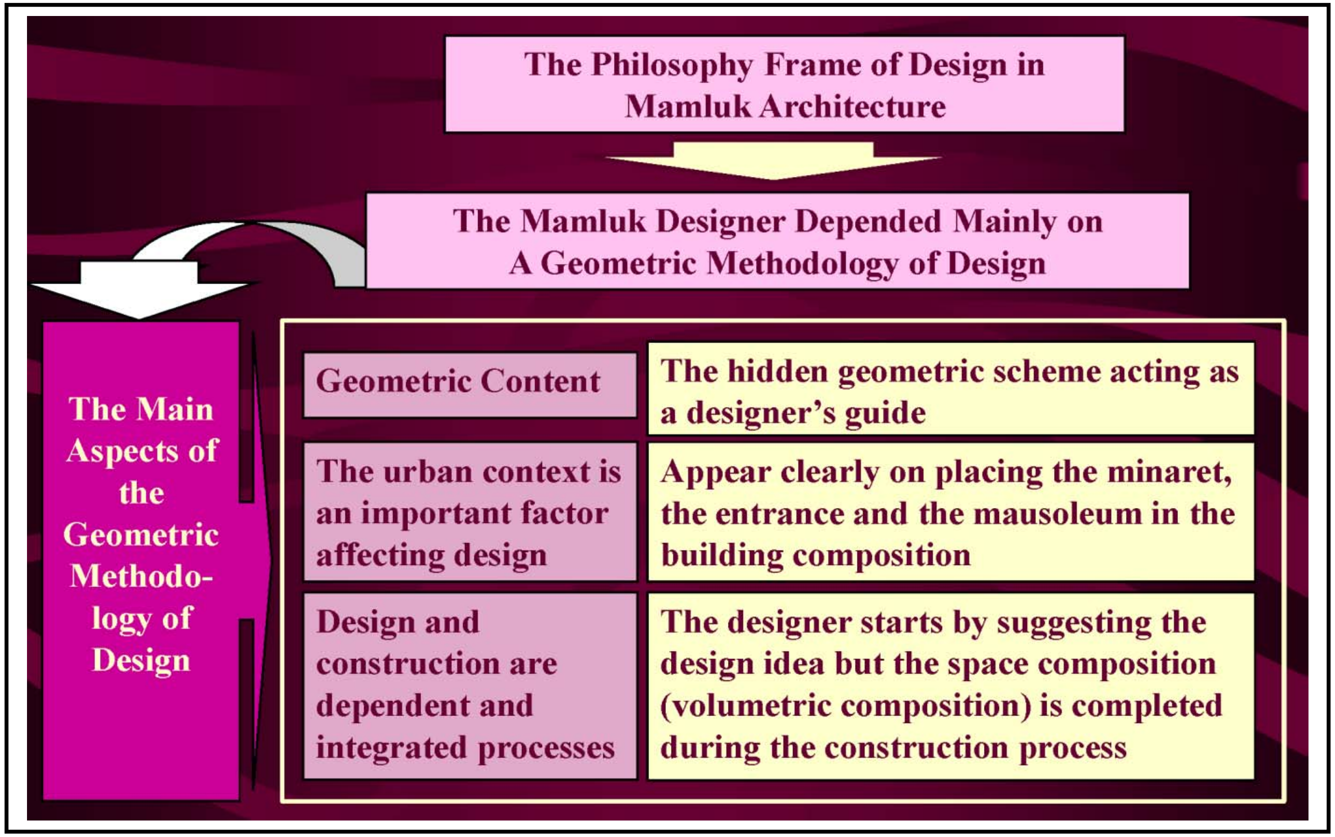


Figure 5-82: The philosophy frame of design in madrasas architecture

Design Method

Geometry

Islamic Architecture

Research Skeleton

Introduction

The first part | The Theoretical Study

Chapter 1: Literature Review

Chapter 2: Mamluk Religious Architecture

Chapter 3: Geometric Design in Madrasa Buildings

Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part | The Analytical Study and the Field Study

Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings

Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A | A Computer-Aided Generator for Madrasa Buildings Design

6. Chapter Six: Conclusion, Recommendations and Proposals for Future Research

6.1. Introduction

The main goal of this thesis is to understand how the Mamluk architect designed madrasa buildings. The geometrical approach has been adopted enabling a re-creation of the geometrical principles and methodologies of the design. In the previous chapters a geometrical methodology of design is followed to re-create the design of madrasas. This argument culminated in the application of the geometric generative technique on some madrasa buildings. In this way, a more realistic interpretation of Mamluk architecture was enabled, through unveiling the geometry inherent in their religious architecture. Throughout the thesis, questions have been raised about the application of the geometric approach as a means of gaining an understanding of the ideas behind the design of madrasas. Some were answered within the process of unveiling findings, while others of a more general or speculative nature were not tackled at all. This chapter attempts to sum up the work as a whole, while at the same time discussing these points.

6.2. Conclusion

The research attempted to develop an analytical approach to understanding the geometry that inspires Mamluk architecture. At the heart of this approach lies the consideration of the relationship between geometry and architectural design, and its application to provide a practical methodology for form making and developing a design method of complex building. The aim of the research is to "outline the geometric concepts of composition and the process of their application in different steps of architecture design process". This is essential not only to the process of madrasa design but also to the understanding of it. This is the means by which the design method of madrasa has sustained its distinct characteristics throughout history despite the culture diversity of the Mamluk world. This research sheds light on the layer of geometry in design resulting from the application of the geometric generative technique on some selected madrasa buildings. The use of geometric methodology in design has succeeded in unveiling most of the principles of design discussed in chapter two and three. In the following points what the research achieved and concluded will be presented.

6.2.1. The Role of Geometry in Madrasa Design

From analyzing madrasa buildings in the theoretical part of this research the role of geometry in madrasa design will become clear, as shown in the following points:

1- The Mamluk architect moved away from static spaces, and instead strove to create more flowing, unified, and flexible spaces. It is said to be a design that manipulates a whole building's function spaces instead of stand-alone spaces. That was by using different methods of composition (superimposition, deformation and aliening method) in geometric forms coupled with a hidden role of geometry leaving a special character on the design.

2- Chapter 4 explained that there is a geometric order in madrasa architecture and there were criteria and principles to be followed, which were derived from that geometric order, and also that the geometric order is translated into a geometrical model which is always associated with madrasa design in different sites in Cairo. Mamluk architects did not create madrasa design, but simply followed the guidance of the geometric order through the emulation of the geometric model. At the same time, within the requirements of each building site they devised the best procedures or methods to apply the geometric model to their design.

3- Studying the geometrical shape grammar in Chapter 3 reflects the geometrical awareness of Mamluk architects, especially in using the geometrical patterns that were produced by the manipulation of regular polygons as the design repeat unit in planes and facades.

4- There are four main aspects that appear from the geometrical analysis of madrasa architecture: the orientation, the axis, the geometric shapes and centre point. Each architect or designer with his own views, capabilities, and imagination sought to come as close as possible, through using these aspects, to the geometric models of design. Thus, the design methodologies were fed from these attempts to reach the perfection of the geometric representation and in turn influenced these architects and designers.

6.2.2. The Educational Preparation to the Mamluk Designer

From the analysis of the educational process in the Mamluk era in Chapter 2 it was found that most Mamluk architects (mu'allimin) or master craftsmen, builders, and all those involved in the craft of building, who were exposed to geometry either directly by having learnt and practiced geometry in a Mamluk education institution or indirectly by being part of the society of building craft, must have reflected their geometry learning in their "creations" through the geometric order inherent in the design method and construction process.

From studying and analyzing the educational system during the Mamluk period in Chapter 2, and concerning the preparation process of the Mamluk architect from the boy stage until he become an architect we can extract two main points:

1- Teaching Geometry in Mamluk Educational System

- Teaching geometry starts at primary education through teaching mathematics. In higher education it branched into four categories: building contracts, science of optics, science of area, and science of weight. Each branch brings benefits in special aspects of madrasa design. The teaching of geometry took place in certain institutions; kuttabs were the mainly primary educational institutions, but schools (madrasa), mosques (masjid), and libraries (maktaba) were the main higher-educational institutions
- The design methodologies' transmission between the architects through the traditional system of apprenticeship resulted in a geometrically aware craftsman passing over the revealed information to the other members of the craft. This furthermore explains how after the establishment of a new method of dealing with a design issue, it becomes part of the tradition – not only that, it becomes the only proper way to deal with it.

2- The Position of Geometry between Sciences in Mamluk Educational System

- In the Mamluk educational curriculum there are three main branches of science: Sharĩ'a-oriented science, Arabic-language-oriented science, and rational science. Geometry comes under the rational science alongside arithmetic, algebra, cosmology and others. The Mamluk architect studied applied and theoretical geometry
- Besides primary education and higher education, which taught geometry, there was craft education. The craft education stages can be divided into three stages, according to the hierarchical rank of craftsman inside the craft society, beginning with the training stage and ending with the teacher's stage. Intermediate is the manufacturer stage. In these stages the craftsman were taught the geometric rules, principles and basis, and the learning process is mainly a training process. The craftsman can attend higher-education institutions after finishing the craft education stages,

6.2.3. The Effect of the Urban Context on the Geometric Design of Madrasas

From the analysis of the effect of the urban context on the madrasa design in Chapter 2, it was found that there were many effects of the urban context on madrasa design. These effects led to the emergence of many elements (architecture or urban elements) and treatments (architecture or urban treatments), which added to the building design, leaving the effects to appear in the final form of the building. These included the emergence of the complex solution in buildings design (this can be clearly seen in cases where the building was divided into two parts across the street), the emergence of the visual continuity in the urban context (this can be clearly seen in the selection of the position of the minaret, the mausoleum and the dome to play the role of the connection elements to the surrounding buildings), the emergence of spatial unifying elements in madrasa design (this can be seen clear in the corridors and courtyard), the emergence of the urban pocket, urban walls, and urban facade in madrasa composition to solve the problems which appear through the conflict in the orientation between the inside spaces and the street, the emergence of the axial articulation form (this can be clearly seen in articulating the building form around the prayer axis which is the direction of Makkah). The emergence of these geometrical elements in Madrasa form and composition demonstrates two points; the first is the clear effect of the urban context on the geometric design of madrasas, the second is the role of geometry in strengthen the mutual relationships between the geometric design of the building and the design of the urban context.

6.2.4. Spatial Design in Madrasa Architecture

Applying the geometric generative technique in madrasa buildings in Chapter 5 revealed that there are three main aspects the Mamluk designer concentrated on in the spatial design in madrasa architecture. The first is the different spatial geometric elements he used, which go to thirteen spatial elements that constitute all the composition of the madrasa. The second is the spatial rules which control the choice of the position of every architectural element in madrasa design. The design of madrasas presented two main types of these rules: orientation rules and positioning geometric rules. The third is the spatial arrangements and spatial determinants in madrasa architecture. According to the spatial arrangements of the spatial elements inside the madrasa buildings there are three types of movement structure that could be identified in Mamluk madrasa: linear, looped and fan-shaped. This reflects the high level of attention that the Mamluk designer gave to the spatial design in madrasas.

6.2.5. The Geometrical Interpretation of the Mamluk Madrasa

The study proposes a new approach to the design of complex buildings in general and madrasas in particular. It proposes a new design method of the existing Mamluk buildings based on a concept of geometric design and stresses geometrical steps of design in order to present the role of geometry in madrasa design.

6.2.5.1. The Geometrical Relationship between the Architectural Elements in Madrasa Design

The research into madrasa buildings found that there were three types of geometrical relationships governed the distribution of architectural elements in the design of madrasa, the geometrical positioning relationship, the geometrical obedience relationship and the integration relationship. These relationships plays in all levels of geometric composition of madrasa building and integrated without any confliction.

In madrasa design, the geometrical relations between shapes are the visual language of the reading of composition. Many of the plans of madrasa spaces vary in size and other attributes, but they are geometrically consistent; their geometrical similarity is producing this sense of unity and continuity in the whole composition. From analyzing the geometrical relationship between the architectural elements in madrasa design in Chapter 3 it can be remarked that its methodology of composition is based on strong geometric principles, which are based on the subdivisions of geometric form in which the alternate shapes' centre points relate to each other with certain angles. This appears to be underlined and inherent guide for its architectural design.

6.2.5.2. The Geometrical Features of Composition in Madrasa Architecture

The geometrical features of composition in madrasa architecture can be summarized in the following points:

- There is an inherent geometric scheme controlling the complex design of madrasa buildings. The design starts with determining the centre points, as references points of the building's main spaces, and then by using the geometrical operation (symmetry, addition, subtraction, rotation,…etc.) the designer could generate all the building design. The main centre points play the role of quickly available reference points for the guideline system of design.
- The first and most central design shape was the square and its derivatives. It was used not only as an additive module, but also in rotation. Then it was as the generator of a dynamic and directional system underlying the designs of complex religious buildings.
- One of the common geometrical features in madrasa architecture was the dependence of design on multiple axes. These multiple axes (either representing symmetry or alignment) were used to create much more complex relationships, like grids, in order to preserve the morphological relationship between the geometric shapes and architectural elements whether they were volumes or plans.

- In most madrasas' design, geometric patterns formulated the design graphical code. Furthermore, geometric patterns made possible an ideal method of shaping areas without resorting to complicated mathematics. Even with the development of geometric shapes, in plan design or facade design, the practical application of geometric patterns is complete in itself. Mamluk architects' designs confirm the role of geometry and geometrical systems as an exact way that governs the composition when measurements are not commensurable through the use of the simplest geometric patterns: square patterns or rectangle patterns, which are used respectively in the design of madrasa plan and facade. For this reason using geometric patterns is without doubt a fundamental aspect of the composition and design of madrasas.
- The design of madrasa contain numerous geometrical features, the three main between them are: the central composition around a courtyard; the location of the entrance, the minaret, and the dome in geometric relation to the street; and the bent entrance's geometrical form which leads indirectly to the main corridor to enter into the central courtyard. This geometric form of the bent entrance achieved two main objectives: function objective and geometric objective. Functionally it maintained complete privacy and reduced noise levels inside the building, and geometrically its geometric model and its fixed form of design gives indication that there is geometric model of the design of the building as well.

6.2.5.3. The Geometrical Methodology of Design and Concepts in Madrasa Design

The architectural composition message relies on decoding architectural form, so to read this message one must recognize the design code, which can be reached by the geometrical analysis of the building composition and through understanding the geometrical methodology in the building design. The research provides an academic source for the major systems of measure connected to the geometry of madrasas, and a ready reference for the numbers and formulae associated with that geometry. The concept of the "Geometric Methodology of Design" investigates the representation of Mamluk practice in a geometric context. It explores the idea of a madrasa as a multifunctional space, through the so-called generative design technique, which is a set of conceptual design guidelines that were derived from the study of madrasa design in this research.

The geometrical methodology of design in madrasas can be summarized in three main points. The first is the Mamluk designer used a geometrical scheme as a guide for the design process. The second is that the design and construction process were linked to each other. The third is that the volumetric design – designing in 3D – in madrasa depended strongly on the use of geometrical principles.

From applying the geometric generative technique on some of madrasa buildings in Chapter 5, the design method can be summarized as follows:

- Madrasa buildings were designed, perhaps even built, from the interior to the exterior, and because of the regularity of the interior it can be contrasted with the irregularity of the exterior. The Mamluk architect depended on geometrical principles to move in his design from interior to the exterior. The existence of these geometrical design principles in all parts of madrasa buildings indicates that all the building forms were generated at the stage of suggesting the design idea with these geometrical principles, which were realized during the Mamluk period.

- The bent entrance, the axis and symmetry are the main parameters that can shape the madrasa plan.
- The Mamluk designer depended on the central courtyard as a generator of the building form in madrasa design.
- The four-iwan plan was a valuable matrix to the Mamluks and they used it in nearly most of the religious buildings of different functions. It was not only just a geometric shape favoured by the Mamluks, but it could also be successfully manipulated within different buildings.
- The Mamluk designers of madrasa buildings limited the use of a circular plan or curved walls. Nevertheless, they compensated the lack of curves in the plan by transforming the square into a circle in domes and minarets when needed. These rounded geometric shapes became the most important and aesthetic element in the visual design of madrasa.

Examples of the benefits resulting from the use of the geometrical approach were crystallized in Chapters 2, 3 and 5 it was shown that the geometric methodology of design allows to penetrate beyond the limitations of utilitarian or aesthetics interpretations into the geometrical domain to arrive at the basis and principles behind these compositions which the Mamluk designer considers in all his designs of madrasa buildings.

6.2.6. A New Layer of Understanding of Mamluk Religious Madrasa Buildings

Madrasas cannot be evaluated unless experienced from both the exterior and interior, because the exterior and interior expressions of madrasa spaces are geometrically integrated. The geometrical role of each is quite different and has its own parameters. The exterior space has to deal geometrically with the human scale and the flow of the street, with reference to the street alignment. The interior space has to deal geometrically with regularity and orientation, also with a certain respect to the street alignment.

The interplay function and form under the affection of geometry in madrasa architecture is the core of Mamluk conceptual design. Although the two factors can be developed and changed individually, they are still connected to each other with geometrical principles of design and this connection does not differ from one building to the next. In a Mamluk madrasa there is unity in the general composition of the building and diversity in the geometrical treatments from one function to another in the same composition. The development of geometric composition from one century to another proves the ability of the Mamluk ideas and concepts to be developed and transformed for further development tools, measurements and schemes.

Scientific discoveries are only links in an unending chain of intellectual endeavour which embraces mankind as a whole. Every scientist builds on the foundations supplied by his predecessors, by those of his own nation or of another, so that the scientific achievements of a particular age or tradition can never be said to belong to it alone. Accordingly, the improvement of design methods goes on and on, from man to man, from age to age, from civilization to civilization. From that, the geometric generative technique suggested here may be found in nations and civilizations before the Mamluk age with a different shape, and the Mamluk designers improved it to make it suitable for Islamic religious teaching, for their society and their culture, or perhaps they invented it and applied it to the design of their madrasas, like in the science, as a means and not an end in itself.

6.3. Benefits of the Geometric Order in Contemporary Architectural Design

Architectural identity is not meant to construct buildings following previous styles, but the lessons that can be learned from the design methods of vernacular architecture, like the Mamluk, should be introduced in new buildings through an effective and flexible design. A design method suggested here can help interpret how to use the successful concepts of the Mamluk built environment on the execution of city centre models and complex buildings.

Nowadays, the Mamluk architect is absent from the design process and the design methods of religious architecture are lost. The production of religious architecture has been exploited by architects who are arbitrary experimenting here and there. It is seen in contemporary architecture that some have relied on the external copying of elements from traditional forms and mixed them together eclectically to create new compositions. The contemporary designer is unaware of the geometry inherent in the traditional form, and so is the user and the viewer. To improve this situation, the contemporary architect has to learn from the examination of Mamluk madrasas how to sort out the features, principles and criteria that are common among them and could not have come about by chance. By maintaining a conscious awareness and intention, he could try to discover the design methodologies that govern them, and respect them in his new designs. If he cannot do that, then he should at least respect what is constant in form and design, not change it by a combination of eclecticism and ignorance.

If it could be agreed on that the geometrical approach is the key to a better and fuller understanding of Mamluk religious buildings, then how, if at all, could this have implications for today's contemporary complex building design in particular and contemporary architecture in general? To answer this question realistically, one first has to examine the design process by which a contemporary complex building is produced; second, to discover the geometry inherent in this process; and third to determine the design methodologies which are extracted and related to the Muslim society, respecting its traditions and circumstances.

6.4. Recommendation

From the previous research and analysis of Mamluk architecture in general and madrasa buildings in particular, the following points can be recommended:

- The methodologies and principles of design of the new religious, commercial and residential complexes can be extracted from the Mamluk designs in order to develop urban-system and building design from the already well-established concept that responded to the needs of society.
- The study highly recommends applying the geometrical methodologies for design before starting complex building design or building new urban centres, not only respecting the geometrical design of the built environment but also learning from the built environment of the past, because this has other dimensions for an architect, besides the practical one of improving design by learning about specific approaches from the past developments, it can also help him on finding various methods for making new designs more satisfactory to the users.
- To reintroduce geometry as a basis for design into modernized society, it would first be necessary to re-educate designers into understanding the great benefits which they will gained through using the geometrical methodology in design.

- To reintroduce the geometric methodology of design into a modernized society, which only sees and believes in an empirically two-dimensional existence, it would first be necessary to re-educate architects and designers into understanding the role of geometry in building design during the Islamic civilization. The research recommends introducing the science of geometry to the students in the faculty and departments of architecture.
- The geometric generative technique produced in this thesis will help in the process of re-creating, re-designing or reserving of the traditional Mamluk buildings in modern society, under the umbrella of a good perception of the Mamluk Egyptian history. Finally, the possibility of a comprehensive understanding of Islamic architecture through the geometrical approach can be achieved only if scholars come to terms with the reality that all traditional knowledge is composed of the union of the qualities and the quantities.
- The process of preserving a historical building must rely on understanding the concept of design. This confirms the importance of understanding the geometrical methodology of design for madrasa buildings before any process of preservation, in order to guarantee the match between the preservation product and the original design of the building. So the conservation has to be based on thoroughly researched design methods.
- Some comprehensive research work must be dedicated to the field of metaphysical and mathematical aspects of Mamluk architecture that have made it possible to uncover a part of the profound knowledge used in Mamluk architecture.

6.5. Suggestions for Future Work

Madrasa buildings are still monuments with a certain cultural message, and a model for further environmental and epistemological research. In this research it is believed that, although the overall examination of the Mamluk madrasa on the level of design method has yielded a deeper dimension to its geometric methodology of design, there are several points still in need of further investigation, some regarding the traditional buildings of past periods within the Islamic history of Egypt, others regarding contemporary architect' understanding of Islamic architecture and the possibility of arriving at feasible design methodologies for complex building design.

This research attempts to start a new area in Islamic architecture in general and in design methods in particular. The following points open a door to researchers to disscus new aspects in the field of "geometry in architecture" and in the historical monuments in Cairo in particular. Mamluk monuments in Cairo suffer from many shortcomings in the process of scientific research and need a great deal more future research. Some ideas suggested to young researchers interested in design methods in the Mamluk era are the following:

- Demonstrating the geometrical methodology of design in urban Mamluk Cairo and presenting how the Mamluk designer used geometrical principles in his traditional urban design concepts (Mamluk forms of urbanism).
- Testing the geometric methodology of design on other periods in the history of Islamic architecture – such as the Fatimid period, and the Ottoman period in Cairo. If compatible results appear, this would raise the question of what caused these similarities, whether it was the sophistication in geometry science during medieval times.

- Suggesting a methodology for the visual design in Mamluk architecture and for the complex buildings in particular.
- Demonstrating the relationship between the geometrical design and the symbolic meaning in the design of Mamluk buildings.
- Analyzing Mamluk architecture as environmental vernacular architecture.
- Discovering the role of geometry in architectural aesthetics.
- How geometry shapes the building morphology.
- Presenting types of geometry in architecture and the role of mixed types of geometry in architectural design.
- Studying the Mamluk heritage with the intention to extract cultural messages from a significant period in order to reveal the vernacular activities and skills, knowledge, crafts, techniques and materials that were used and were responsible for the monumentality of the entire built environment.
- Comparing Mamluk architecture with the Fatimid and Ayyubid architecture, explaining how the Mamluk borrowed a great deal from the two styles and explaining how they manipulated the borrowed architectural features in new compositions.
- Evaluating contemporary Islamic architecture in Cairo as well as the Muslim world to make the general public, as well as designers, more aware of the geometry void that contemporary architects have thrust onto Muslim society in the name of modern and post-modern Islamic style.
- Using modern geometrical analysis of historical buildings as an alternative tool to uncover the profound knowledge of traditional master builders in their works, to improve the modern theories of design and to set new design criteria.
- How does the user perceive the messages behind the design? Did the buildings do their job in transferring the architects' and designers' messages and intentions to pedestrians and users? The trickier question is whether the same design produced in another time would still convey the same message to the user. Future research should try to read what there is between lines in the design of these buildings.

Finally, there is a need to examine the possibility of incorporating design methods of Mamluk Cairene buildings in contemporary designs of complex building. This should be prompted by restore to Egyptian architects their Islamic heritage of Mamluk design, involving the active co-operation of informed clients and users and skilled craftsmen. What is required is neither faked tradition nor faked modernity, but an architecture that will be the visible and permanent expression of the character of a community. This suggests finding a new "bridge" that would connect traditional Islamic architecture with contemporary architecture in the design methods or features common to both, in which the architects could find a familiar point of reference in order to enlarge their understanding of new designs.

Research Skeleton

Design Method

Geometry

Islamic Architecture

Introduction

The first part — The Theoretical Study

- Chapter 1: Literature Review
- Chapter 2: Mamluk Religious Architecture
- Chapter 3: Geometric Design in Madrasa Buildings
- Chapter 4: Towards a Geometric Methodology of Design in Islamic Architecture

The second part — The Analytical Study and the Field Study

- Chapter 5: Applying the Geometric Generative Technique of Madrasa Design in the Case-study Buildings
- Chapter 6: Conclusion, Recommendations and Proposals for Future Research

Appendix A — A Computer-Aided Generator for Madrasa Buildings Design

7. Appendix A: A Computer-Aided Generator for Madrasa Buildings Design

7.1. Introduction.

The research focuses on the relations between architecture and geometry. This relation becomes very clear if a computer aided presentation tool is used to present the role of geometry in the building design process. Therefore, this chapter presents the computer aided generator for Mamluk Madrasa building design

The main hypothesis of this study is that the logic of building design and space disposition can be represented as a finite set of generative design steps and shape compositional principles. So the main scope of this chapter is to develop a computer-aided system that can describe, analyze, and generate a building two-dimensional plan, building space disposition design, building facade design, beside presenting a geometric order in building decoration design, by applying productive steps of composition.

The derived design presents possibilities that may inspire the designer by using a Top-Down approach. In this approach, a design problem is studied as a whole unit to derive the basic constituent elements and relationships underlying its structure. Such a derivation is based on the understanding of the compositional principles underlying the appearance of designed buildings.

The main goal of this chapter is to formulate a structured and systematic framework for analyzing the form and for generating the design of the traditional building in Islamic architecture, based on the geometrical analysis, functional analysis and morphological analysis of the buildings.

The program is implemented on the educational buildings (Madrasa) in Mamluk architecture as a case study

7.2. The Theoretical Frame Work for the Generative System

Mamluk Madrasas represent some of the most beautiful examples of the Islamic architecture. Despite their historical and aesthetic value, they have not received enough attention from researchers, especially in the areas of systematic analysis of their morphological structure or design.

The designs are analyzed by decomposition them into a vocabulary, which represents the lexical level and rules and according to this, the spatial relations or arrangements of vocabulary elements in space, are identified in terms of the decomposition of the original designs. As a result of the re-synthesis of the decomposed elements, the software generates the original designs of the buildings.

The framework outlined here is developed into a computer implementation, which is designed to be viable for complex building design problems. The computerized framework is designed to enable designers to understand existing designs and help them generate new forms that have the same style.

The computerized version of the generative system reflects the multi-phased characteristics of design principles in order to permit a rapid generation of Mamluk Madrasa prototypes through an incremental and lucid step-by-step sequence of selecting steps and shapes.

7.3. Description of the Computer-Aided Generator Program

The program provides the capability to interactively generate Madrasa building Designs. It is favoured for many building types because it produces a clear, easy, and systematic design fit to simple and complex buildings.

The goal of this program is not to provide ways and ideas to solve design problems in architecture, but it is a means to understand the relations between the components and elements of the building and to assist in discovering of new ways to solve design problems of similar buildings in the contemporary architecture.

One of the advantages of this program is that it allows the centre of attention to shift from the mechanisms of solution to the relations between composition components around which the study revolves.

7.3.1. Programme Language Description

The Computer-Aided Generator software is programmed in Borland Delphi for Windows.

The Menu Bar structure and functions follow the Windows standards. Those commands that can not be used in a given situation are available for the users, presented in a dimmed form on the screen.

This program generates Madrasa buildings' design through presenting the scenario of a solution divided into main steps, so that the program consists of three main menus; each one of them contains three or more sub-menus.

7.3.2. The Programme Interface

To generate or reconstruct a building space design or building facade design, the program starts by analysing and classifying the main building elements, their relations and possible compositions. Because of the large number of steps to generate the building design (space and facade design), the program commands are designed in phases and are decomposed into a sequence of steps. The codes of the generative system are written in the DELPHI language for windows. This saves time in rewriting some existing programming routines and is very suitable for graphic applications.

The interface of the program consists of three main menus, which represent the different steps of the derivation process of three main aspects of the building. The first main menu is used for presenting geometric order in building space design. The second main menu is used for presenting the geometric order in building facade design. The third main menu is used for presenting some methods which demonstrate the geometric order in building decoration design. The menus are designed in a simple and clear format, as shown in the following figure: -

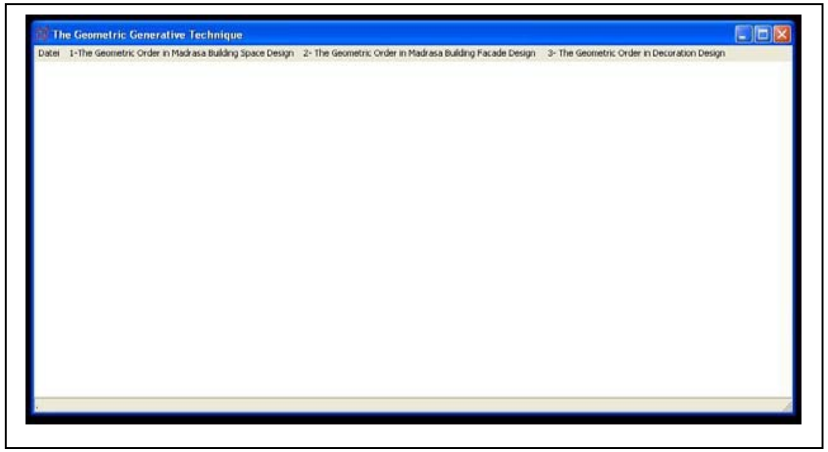


Figure 7-1 The program interface three main menu

The first menu: "**The Geometric Order in Building space Design**". This menu has three submenus:

1- The Geometric Generative Technique Main Components. This submenu branches into three submenus: the geometric generative technique language, the basic Islamic religious building design principles and the hidden geometric design system.

2- The Geometric Generative Technique Steps. The function of this submenu is presenting the six steps by which the designer can generate the Madrasa building space design.

3- The Case Study Buildings. This submenu includes three case study buildings. The geometric generative technique is applied on them in order to generate their space design.

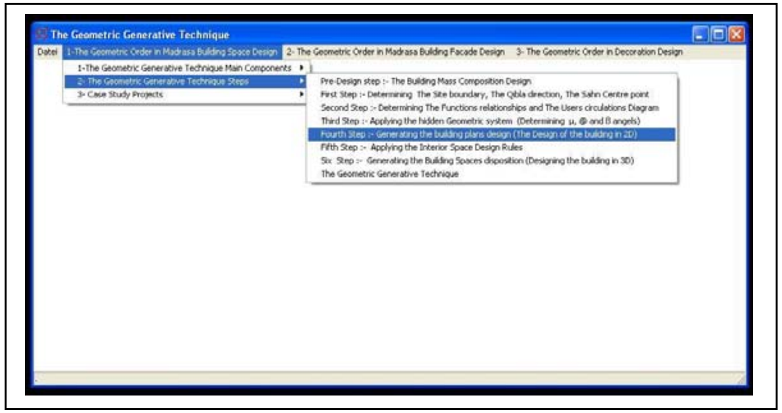


Figure 7-2 The first main menu and its three sub-menus

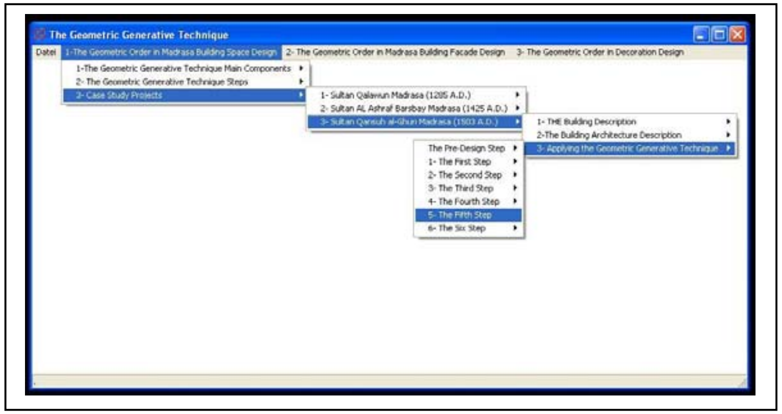


Figure 7-3 The six steps of geometric generative technique for building space design

The hierarchical organization of the Mamluk Madrasa program interface is shown in the following figure.

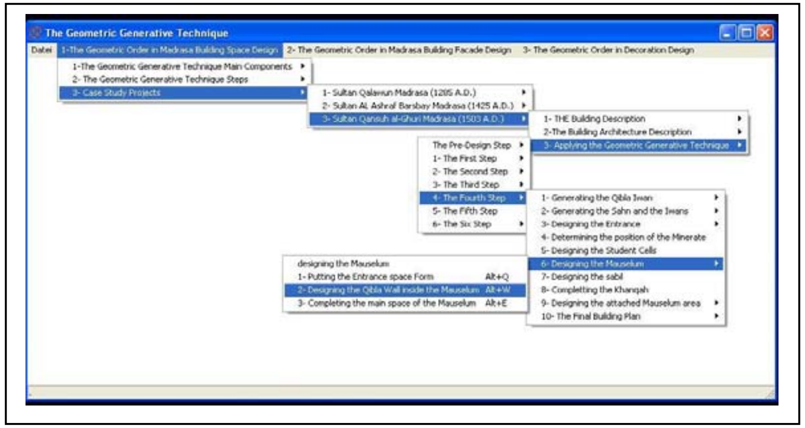


Figure 7-4 The sequence of the main-menus and sub-menus inside the program

The second main menu: “**The Geometric Order in Building Facade Design**”. This menu has two submenus:-

1- The geometric generative technique main components: there are two main components as follows

a- Islamic Design Principles for Facade Design. This submenu presents a set of Islamic principles for facade designing,

b- Geometric Generative Technique Steps for Facade Design. The main function of this submenu is to demonstrate the thirteen steps by which the designer can generate the Madrasa building facade design.

2- The Case Study Projects. This submenu demonstrates the application of the geometric generative technique for generating facade design in three case study buildings.

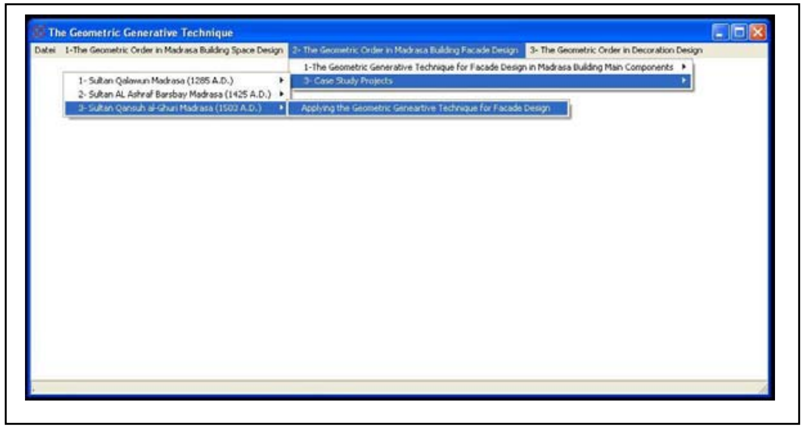


Figure 7-5 The second main menu and its two sub-menu

The third main menu: “**The Geometric Order in Building Decoration Design**”. This menu has five submenus. Each one demonstrates a method for decoration pattern design and every method includes two submenus as follows: - the first is the method notion and the second is the method steps applied on one case study decoration pattern.

Method 1: Abu’l-Wafā al-Buzdjāni (ca. 940–998).

Method 2: E. Hanbury Hankin, “polygons-in-contact” technique, 1925.

Method 3: Isam El Said, “Compass and Ruler Method”, 1962.

Method 4: A.K. Dewdney, “The Over Under Rule”, 1993.

Method 5: Aljamali, “Normalization and exploration design method”, 2003.

Method 6: Eric Broug, “Step-by-Step” guidance, 2008.

When the user invokes any of the menus, the box is presented on the screen, giving the user two options to choose from: the method notion and the method example. Once one of them is selected, the data sheet is displayed and presented according to the first selection the method notion and according to the second selection, the method steps are displayed sequentially.

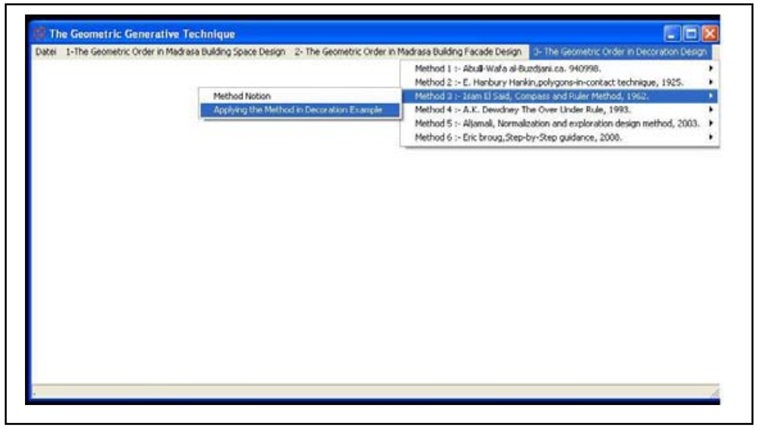


Figure 7-6 The third main menu and its six sub-menu

All three main menus and the additional submenus are illustrated in the hierarchical organization diagram shown in Fig.4.

Figure 7-7 The Program Menu hierarchical organization

7.4. How to Use the Program (Applying the Program on Case Study buildings)

The program, as shown before consists of many sub-menus which come under the main menu

These main menus contain two kinds of sub-menus. The first one demonstrates the geometric generative technique for the building space design or the building facade design. The second kind presents the application of the geometric generative technique on the case study buildings.

When the generative system steps end, three a final windows appear. The first one presents the building final design in 2D with its hidden geometric system. The second final window presents the building final design in 3D. The third presents the building main facade final design with its hidden geometric system.

It is shown how the program generative process of the space design and the facade design functions in three buildings: Madrasa of Sultan Qalawun, Madrasa of Sultan Al-Ashraf Barsbay and Madrasa of Sultan Al-Ghuri as a case study. The rest of the case study buildings are founded on the program CD.

7.4.1. Applying the Geometric Generative Technique in Madrasa of Sultan Qalawun

The following photos are the program's interface which presents itself to the user during the work with the program.

a- Applying the Geometric Generative technique in Madrasa of Sultan Qalawun Space design

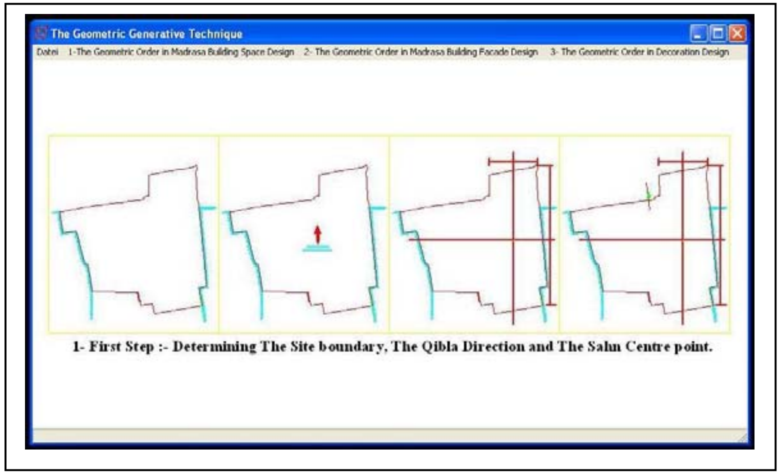


Figure 7-8 Determining the site Boundary and Sahn centre point

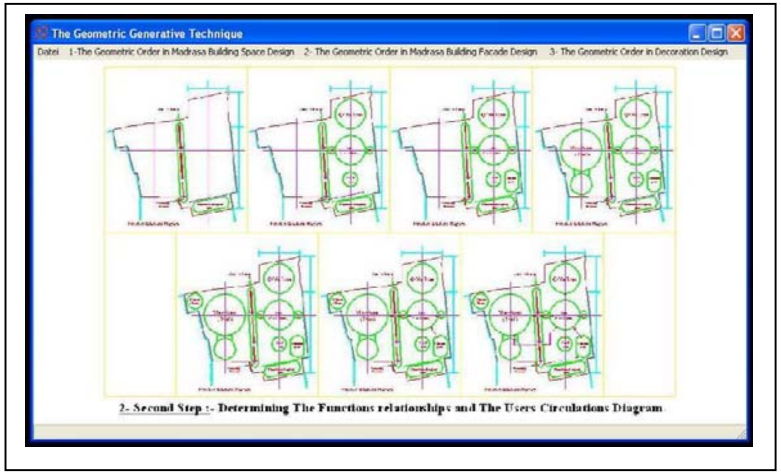


Figure 7-9 The Users and Functions Relationship Diagram

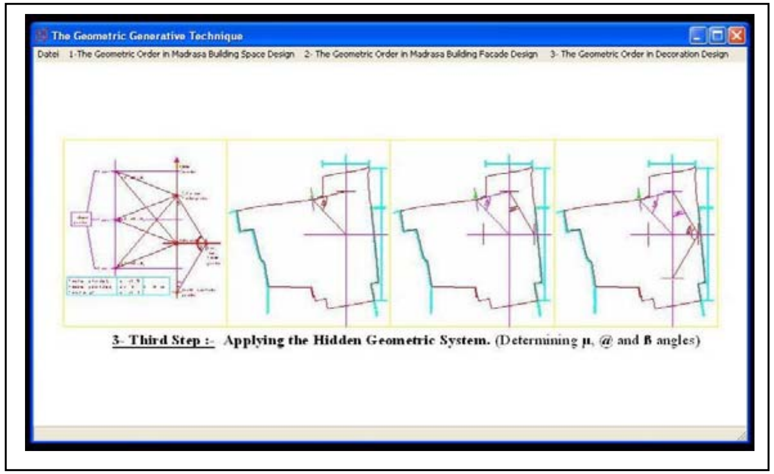


Figure 7-10 Applying the Hidden Geometric Design System

The fourth step consists of the following nine sub-steps

Figure 7-11 (1) Generating the Qibla Iwan

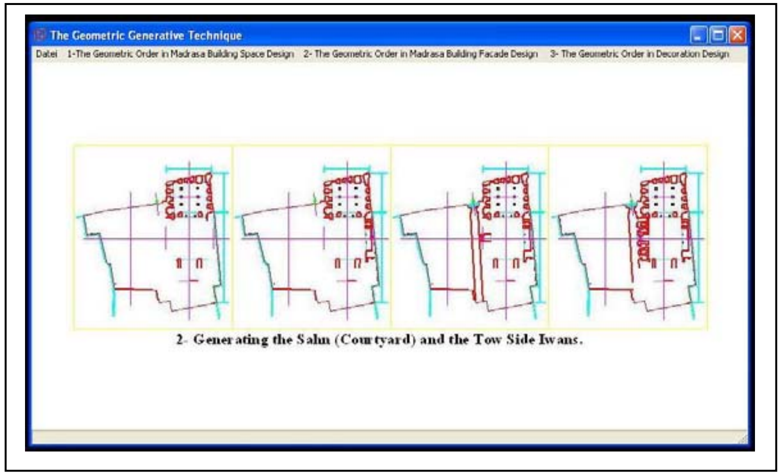


Figure 7-11 (2) Generating the Sahn and Side Iwans

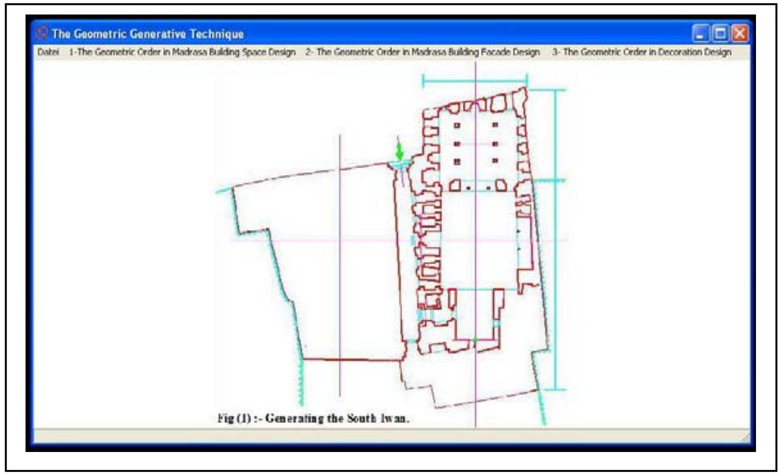


Figure 7-11 (3) Generating the South Iwan

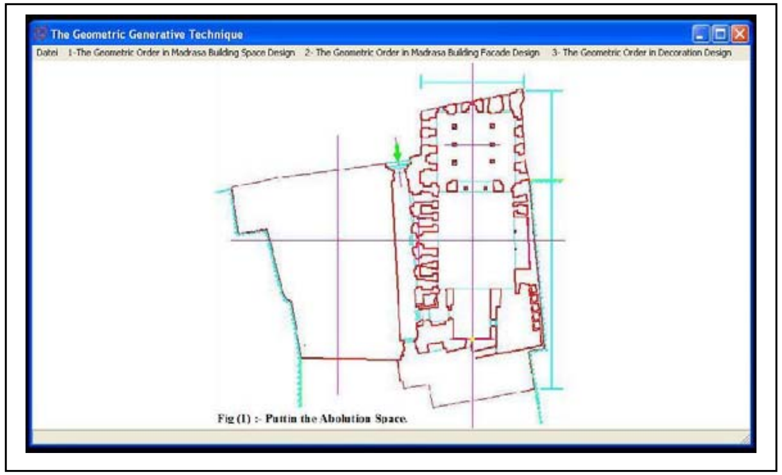


Figure 7-11 (4) Adding the Ablution Space

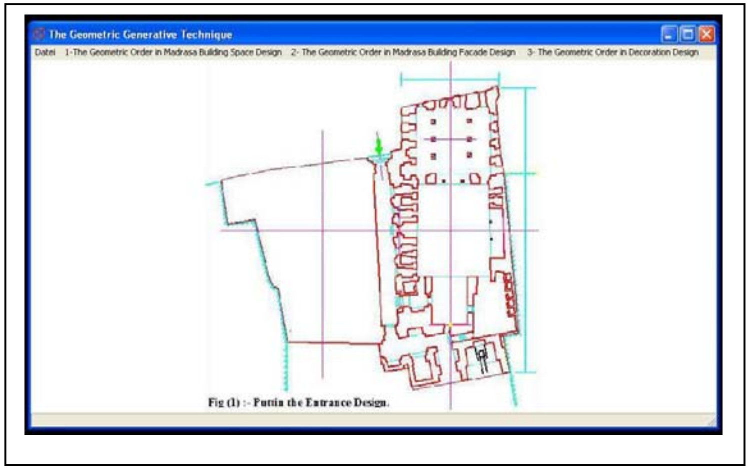


Figure 7-11 (5) Adding the entrance design

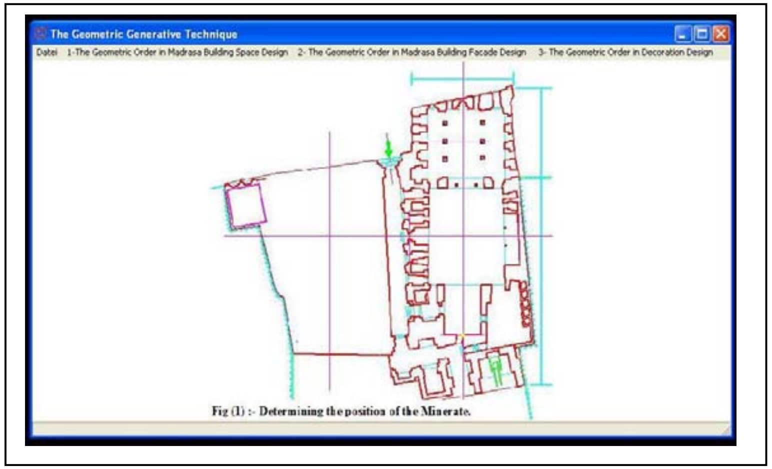


Figure 7-11 (6) Adding the Minaret position

Figure 7-11 (7) Designing the Mausoleum

Figure 7-11 (8) The building plan with the hidden geometric design system

Figure 7-11 (9) The Final building plan

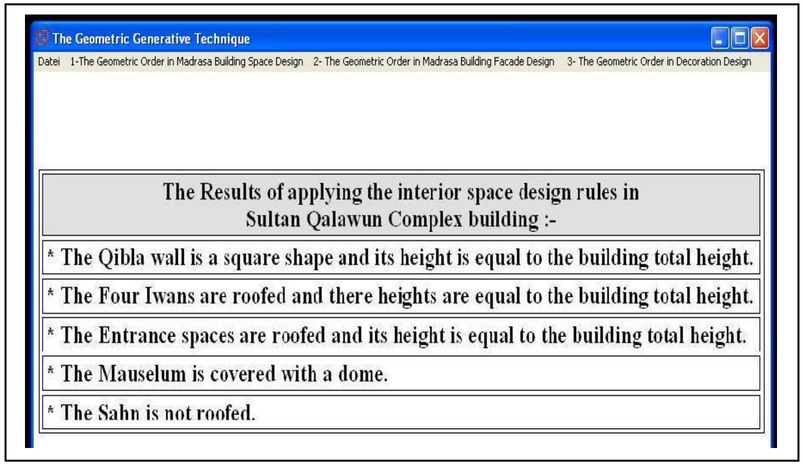


Figure 7-12 The interior space design rules

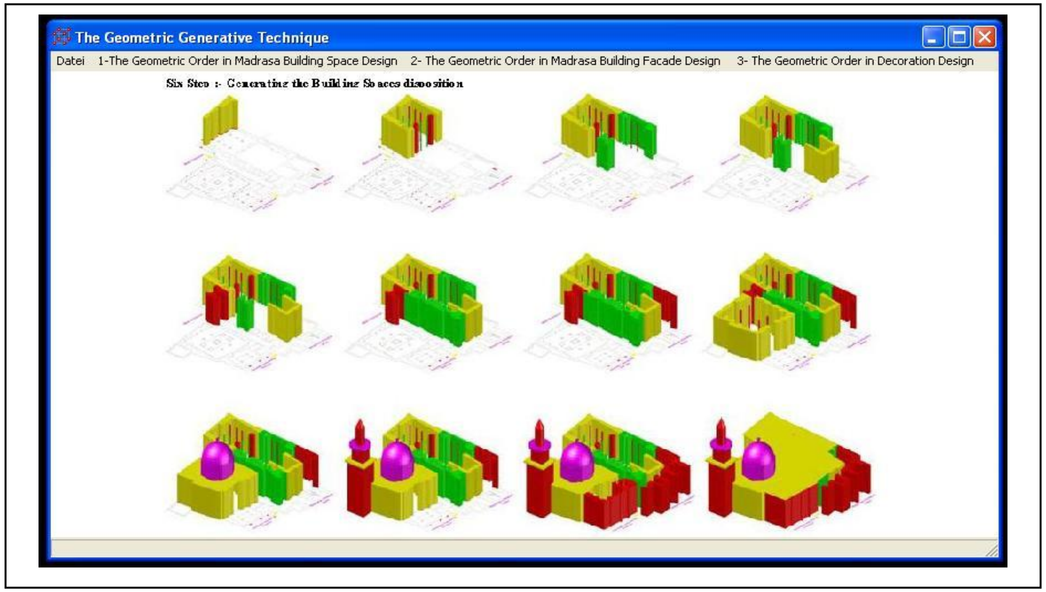


Figure 7-13 The building construction steps

b- Applying the geometric generative technique in Madrasa of Sultan Qalawun facade design

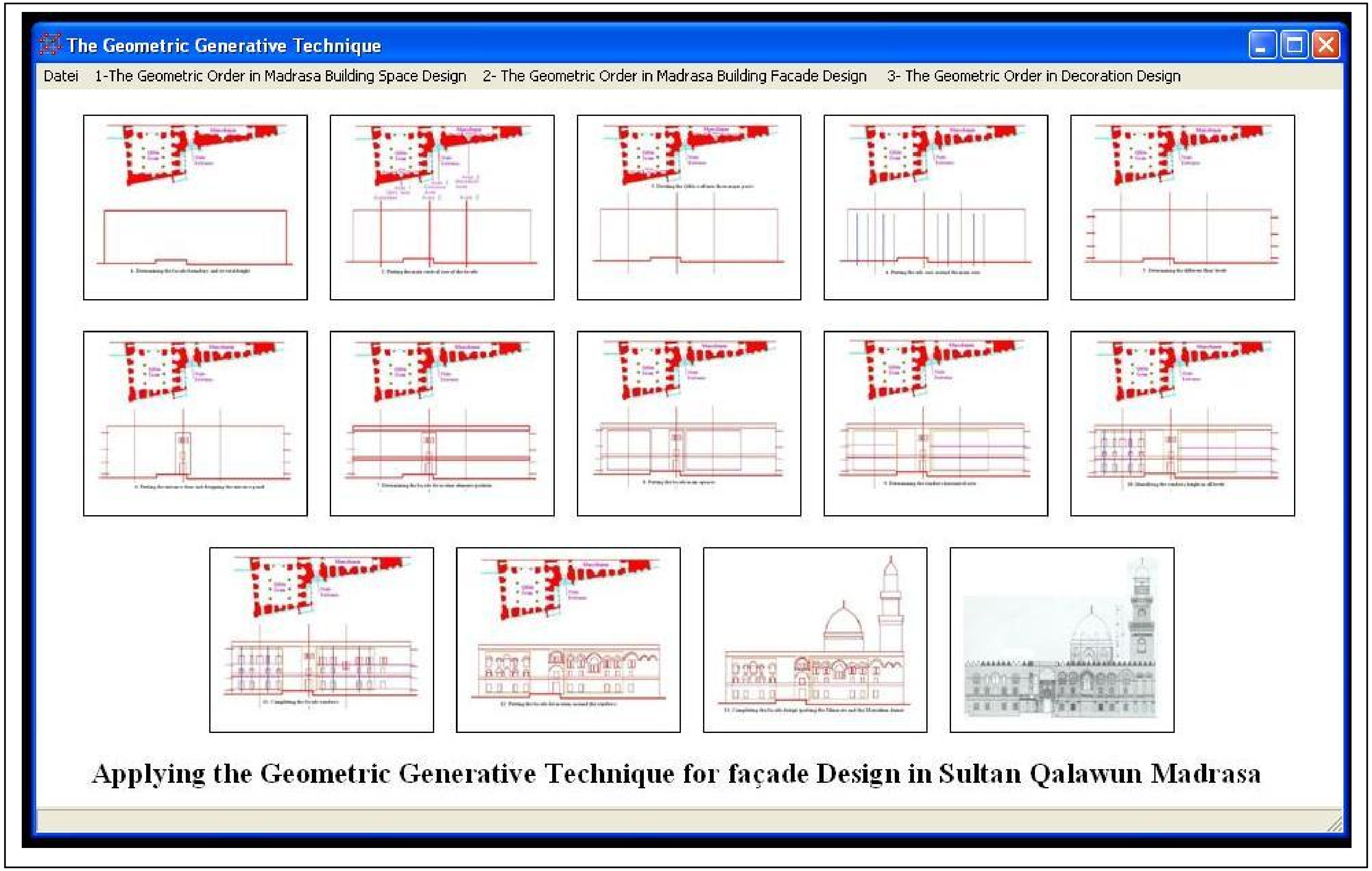


Figure 7-14 The geometric generative technique for facade design in Madrasa of Sultan Qalawun

7.4.2. Applying the Geometric Generative Technique in Madrasa of Sultan Al-Ashraf Barsbay

a- Applying the geometric generative technique in Madrasa of Sultan Al-Ashraf Barsbay Space design

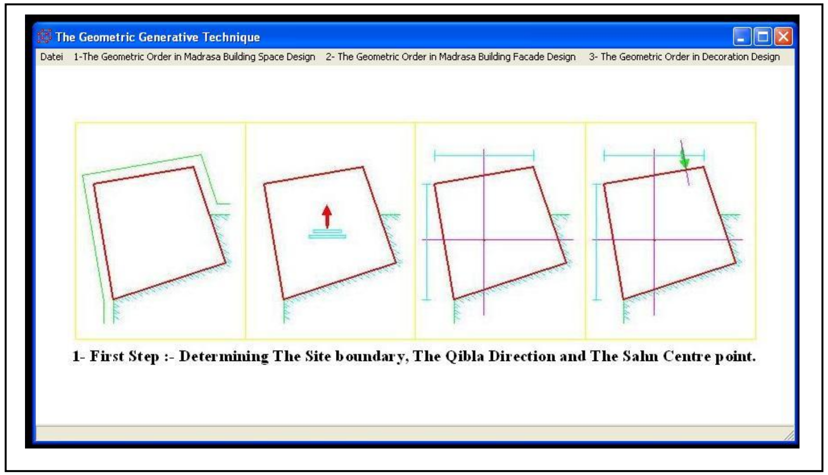


Figure 7-15 Determining the site Boundary and Sahn Centre Point

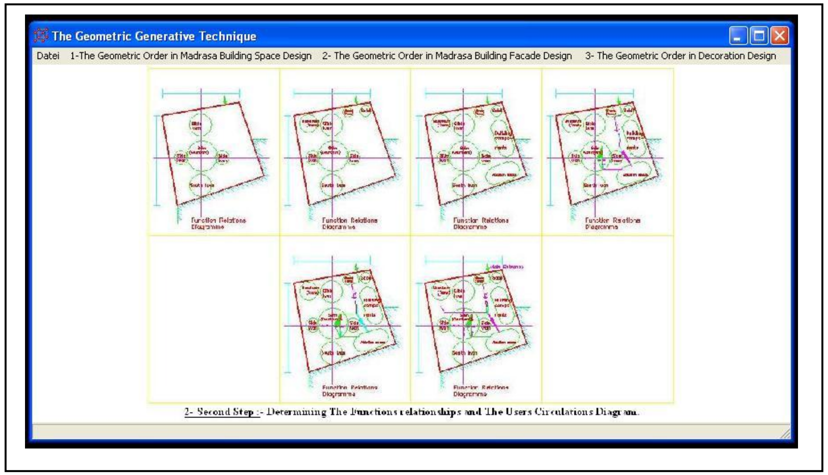


Figure 7-16 The Users and Functions Relationship Diagram

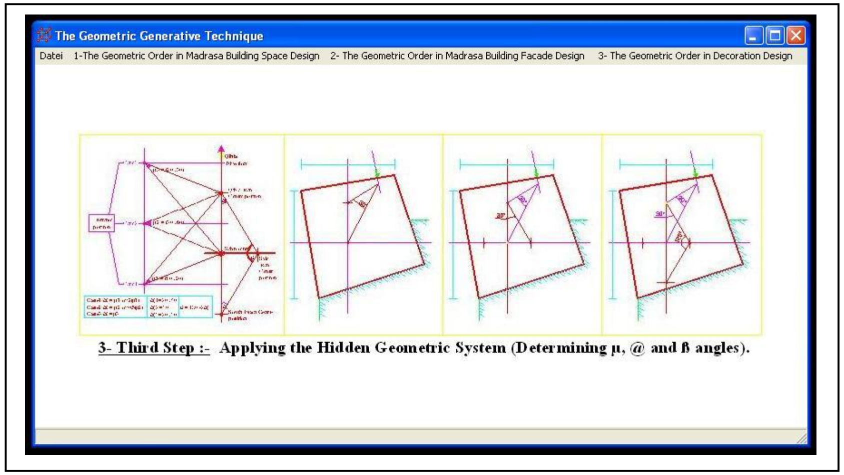


Figure 7-17 Applying the Hidden Geometric Design System

The fourth step consists of the following ten sub-steps

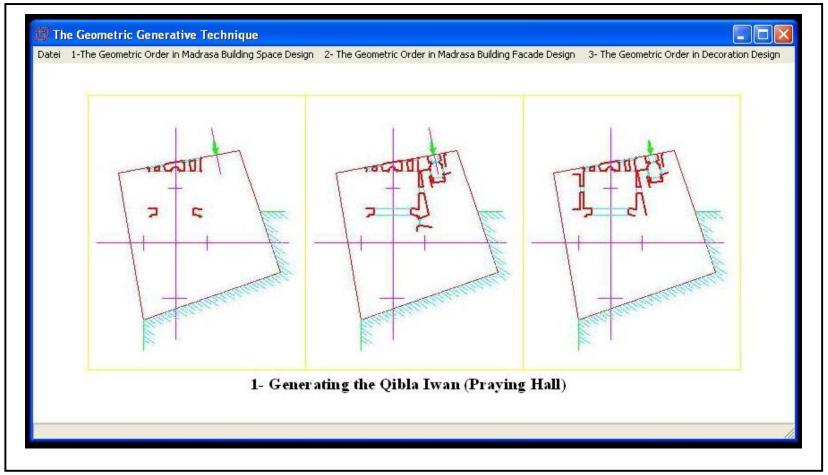


Figure 7-18 (1) Generating the Qibla Iwan

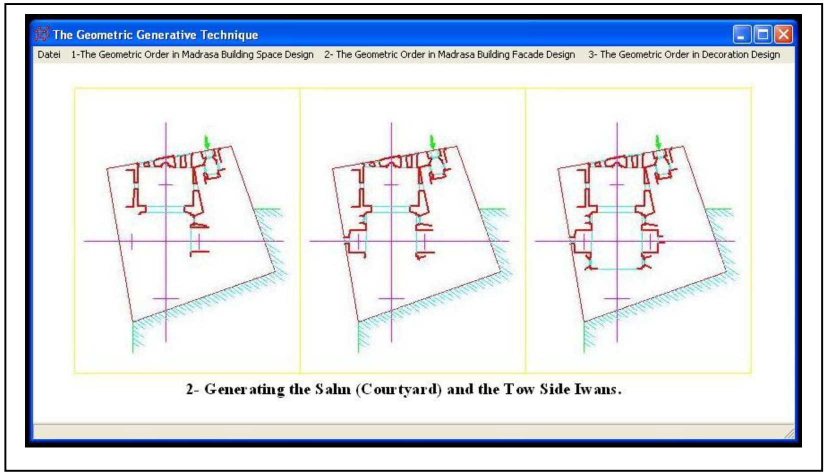


Figure 7-18 (2) Generating the Sahn and Side Iwans

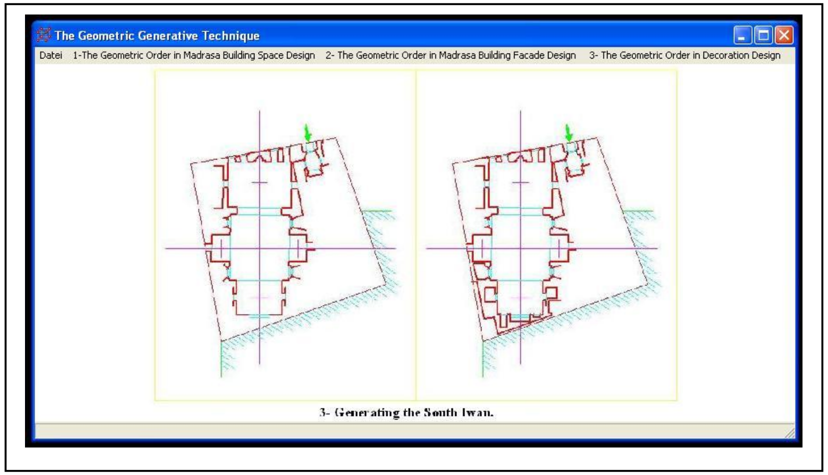


Figure 7-18 (3) Generating the South Iwan

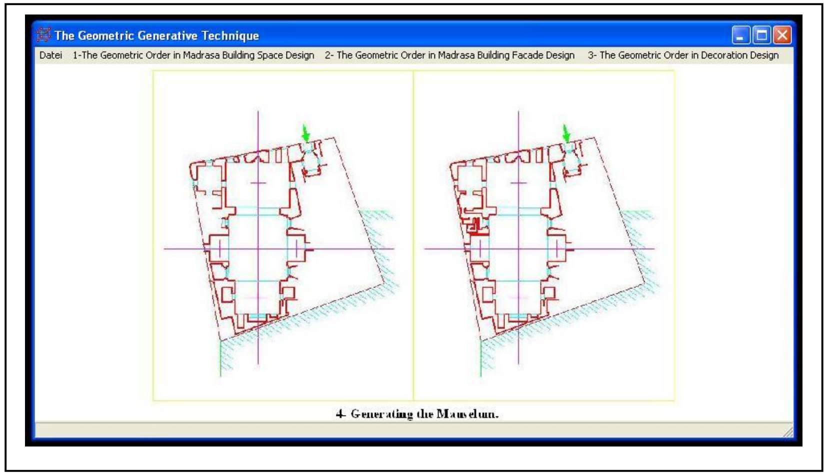


Figure 7-18 (4) Designing the Mauselum

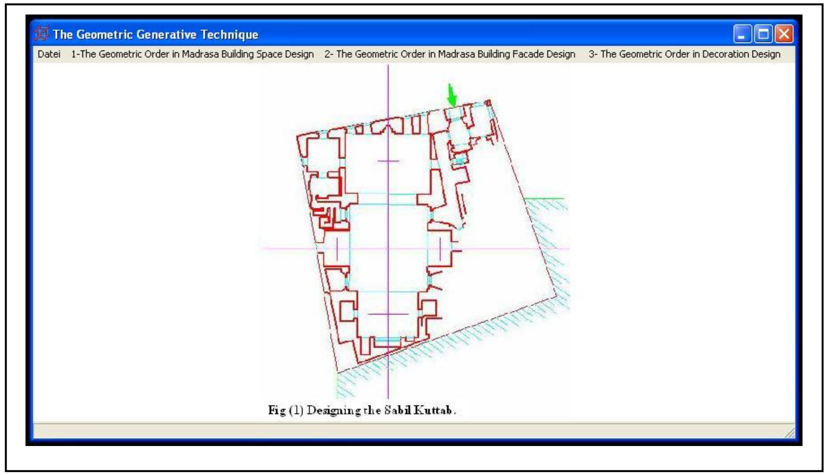


Figure 7-18 (5) Generating the Qibla Iwan

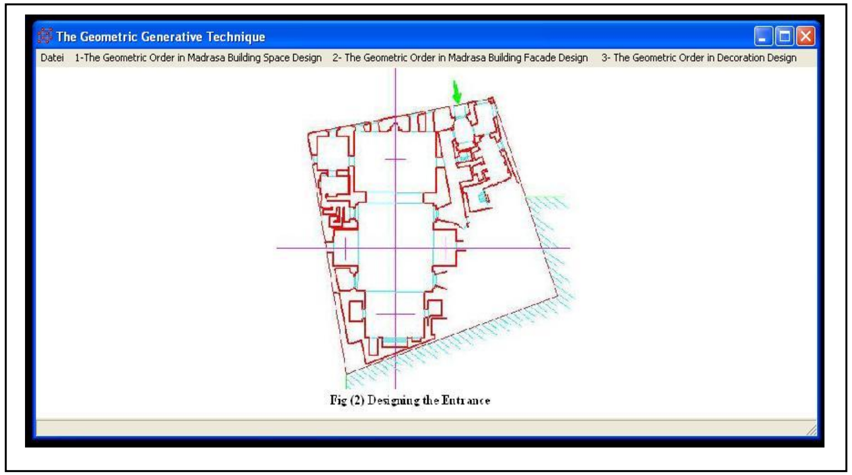


Figure 7-18 (6) Generating the Sahn and Side Iwans

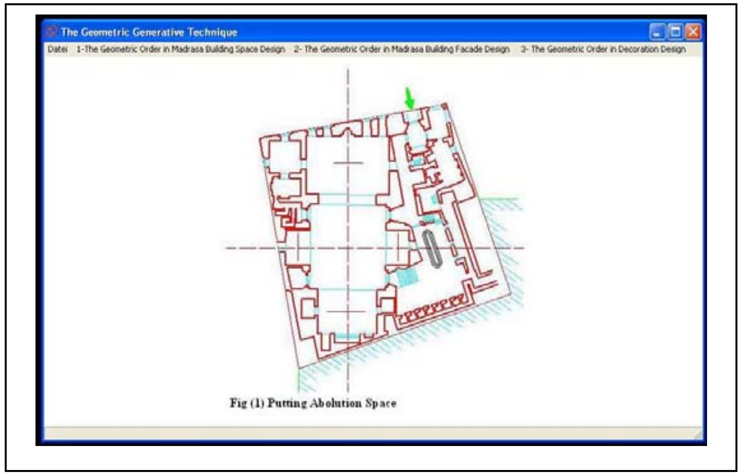


Figure 7-18 (7) Generating the South Iwan

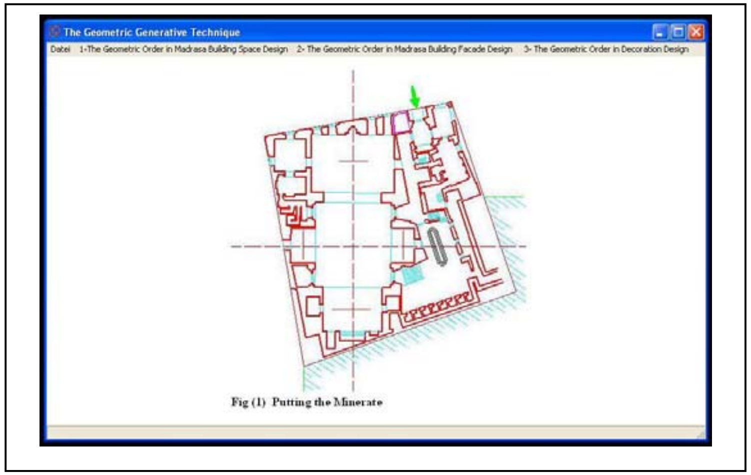


Figure 7-18 (9) Designing the Mauselum

Figure 7-18 (10) The building plan with the hidden geometric design system

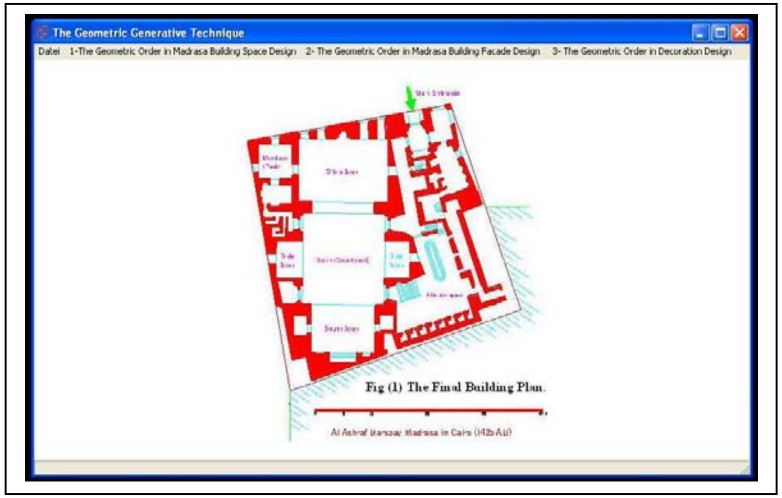


Figure 7-18 (11) The final building plan

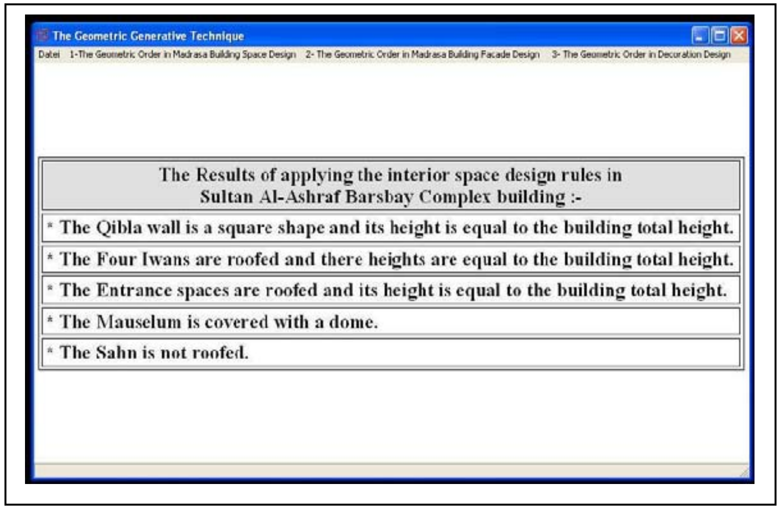


Figure 7-19 The interior space design rules

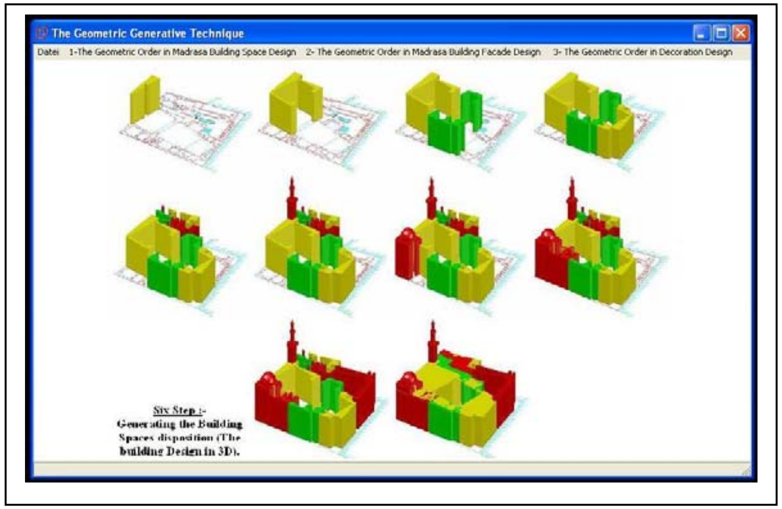


Figure 7-20 Figure 6-20 The building construction steps

b- Applying the geometric generative technique in Madrasa of Sultan Al-Ashraf Barsbay facade design

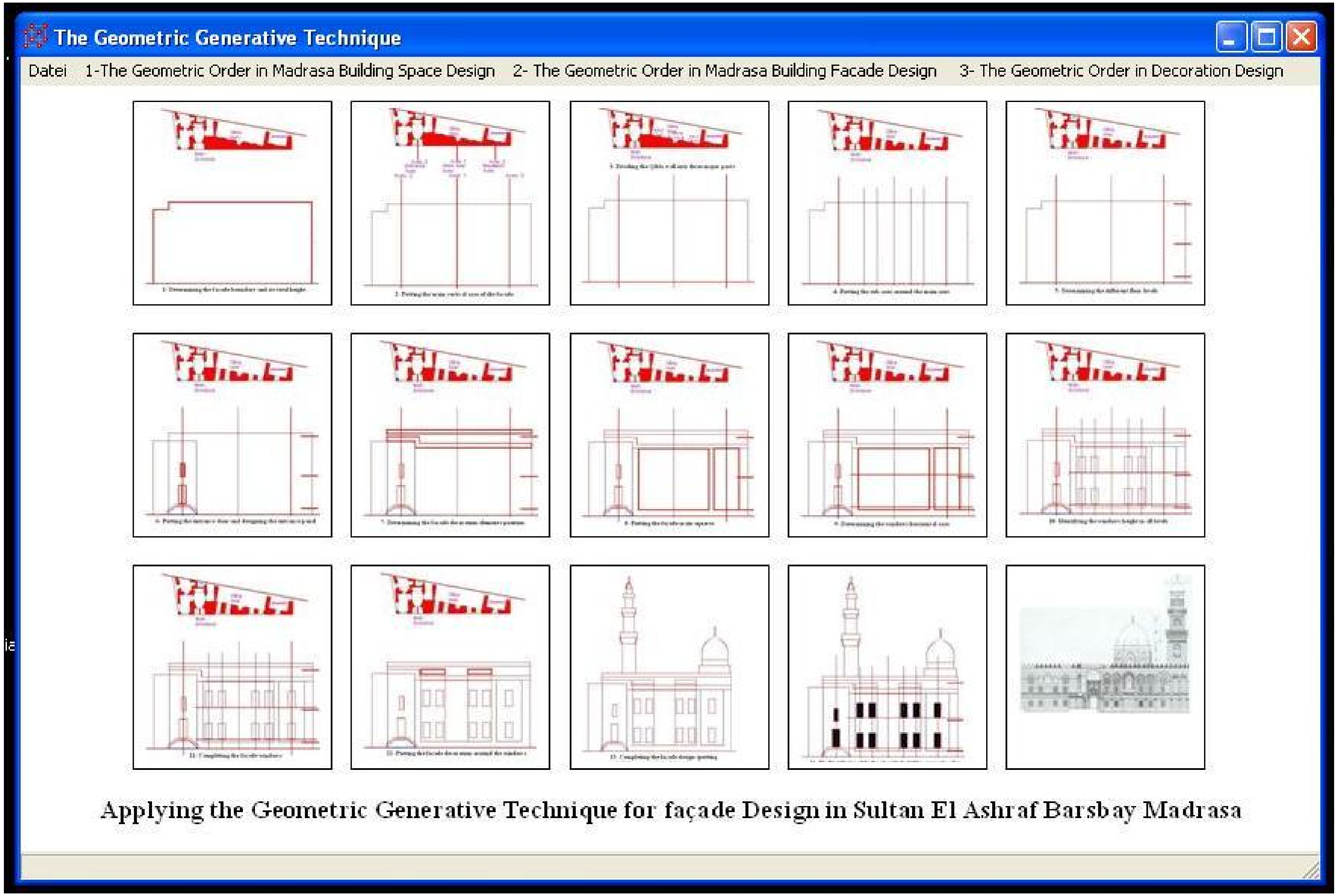


Figure 7-21 The geometric generative technique for facade design

7.4.3. Applying the Geometric Generative Technique in Madrasa of Sultan Al-Ghuri

The following photos are the program's interface which presented itself to the user during the work with the program.

a- Applying the geometric generative technique in Madrasa of Sultan Al-Ghuri space design

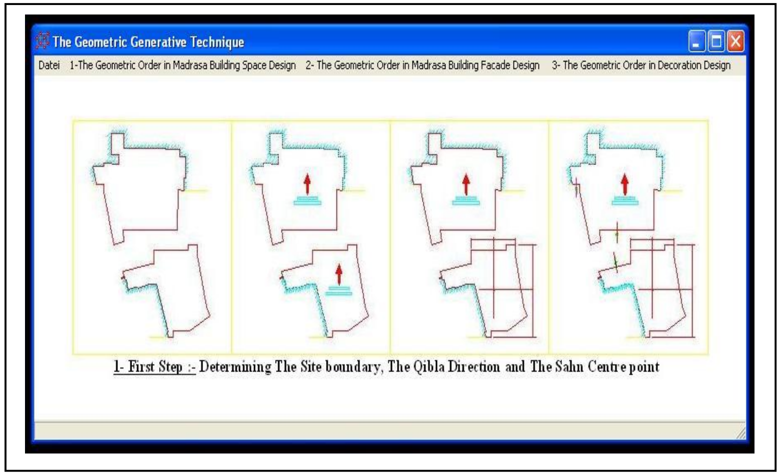


Figure 7-22 Determining the site Boundary and Sahn Centre Point

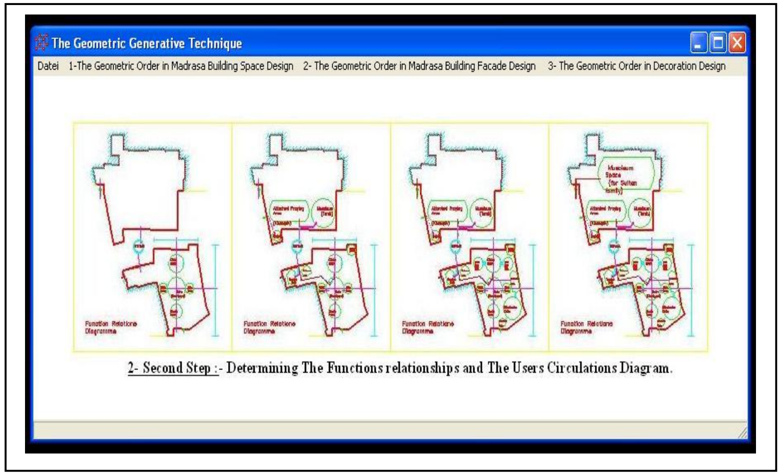


Figure 7-23 The Users and Functions Relationship Diagram

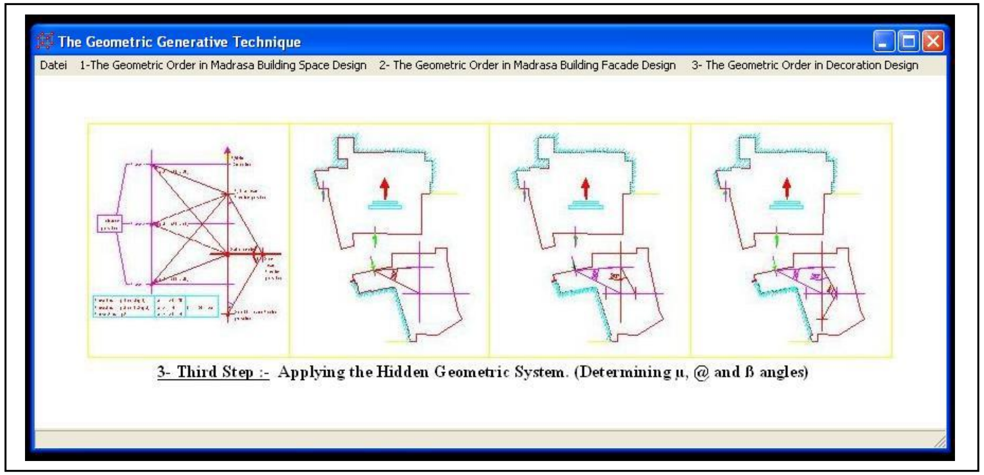


Figure 7-24 Applying the Hidden Geometric Design System

The fourth step consists of the following nine sub-steps

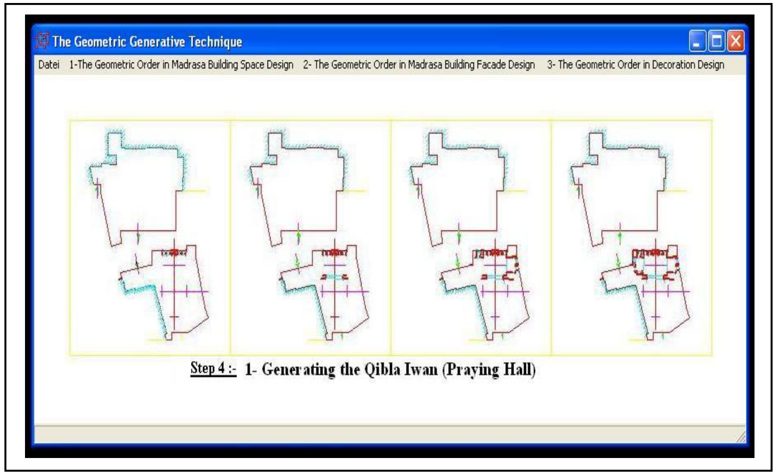


Figure 7-25 (1) Generating the Qibla Iwan

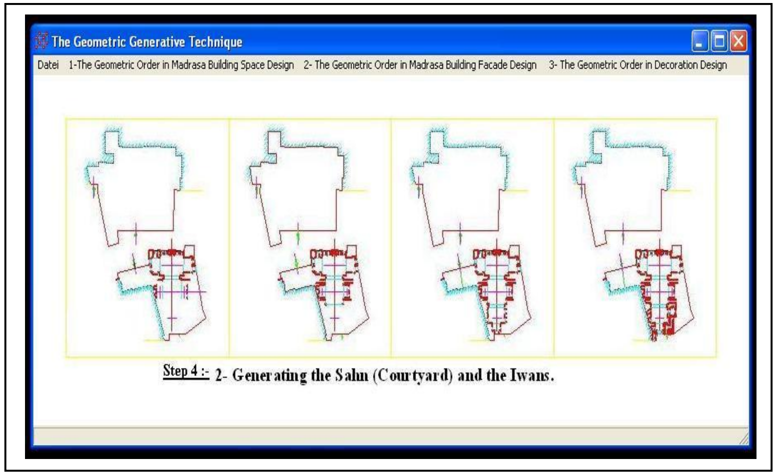


Figure 7-25 (2) Generating the Sahn and the Iwans

Figure 7-25 (3) designing the Entrance

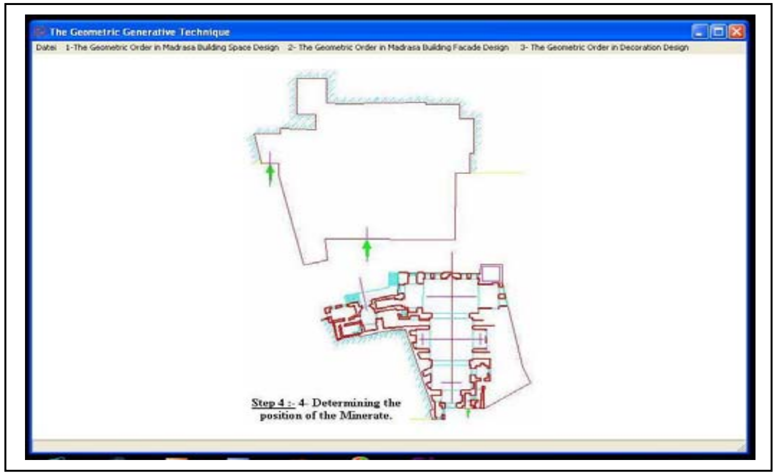


Figure 7-25 (4) Putting the Minaret position

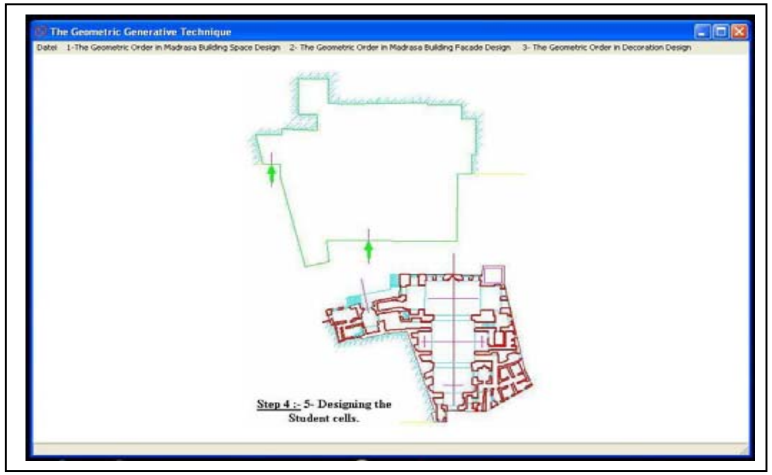


Figure 7-25 (5) Designing the Students Cells

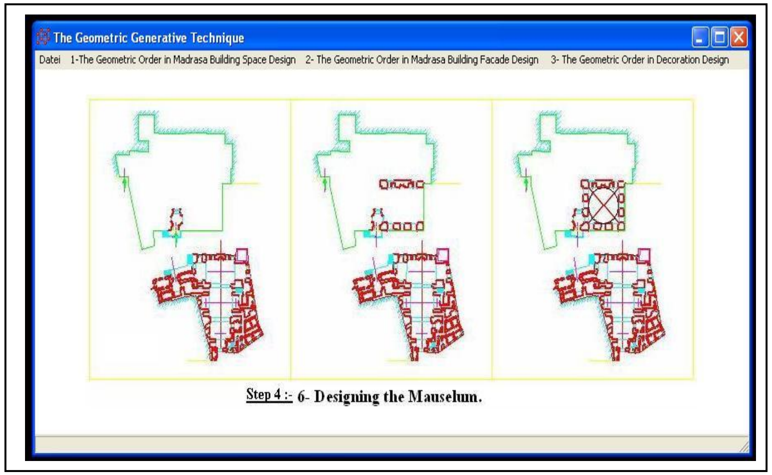


Figure 7-25 (6) designing the Mauselum

Figure 7-25 (7) Designing the Sabil

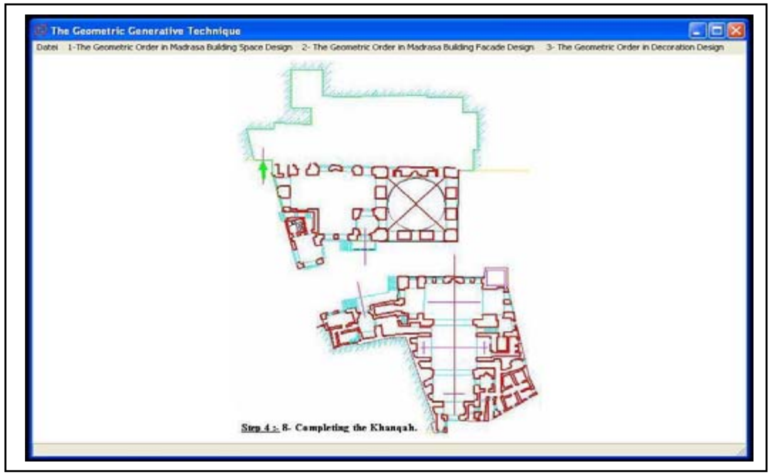


Figure 7-25 (8) Completing the Khanqah.

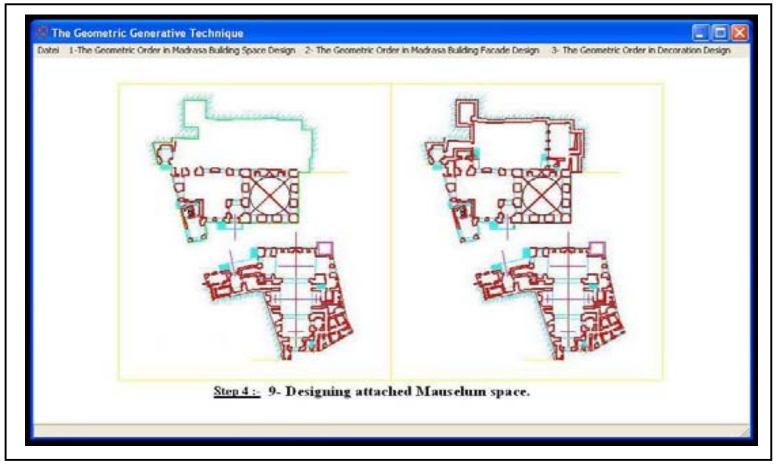


Figure 7-25 (9) The Final building plan

Figure 7-25 (10) The Final building plan

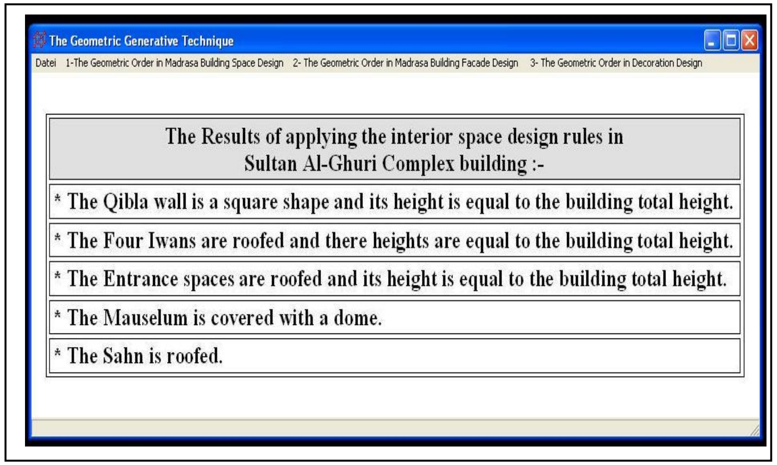


Figure 7-26 The interior space design rules

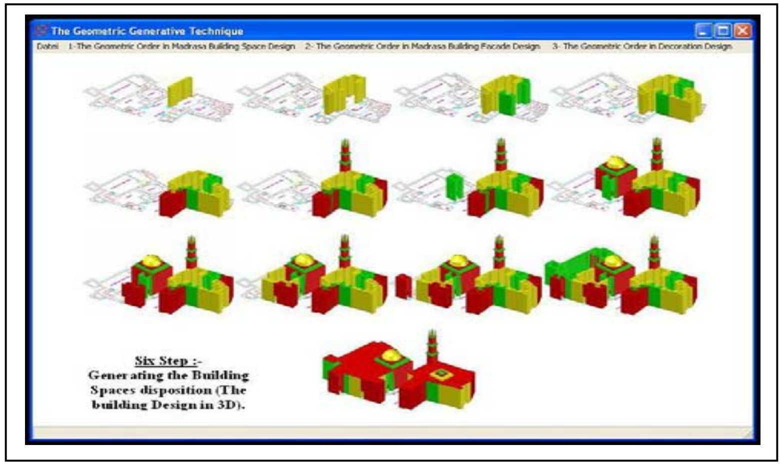


Figure 7-27 The building construction steps

b- Applying the geometric generative technique in Madrasa of Sultan Al-Ghuri Facade design

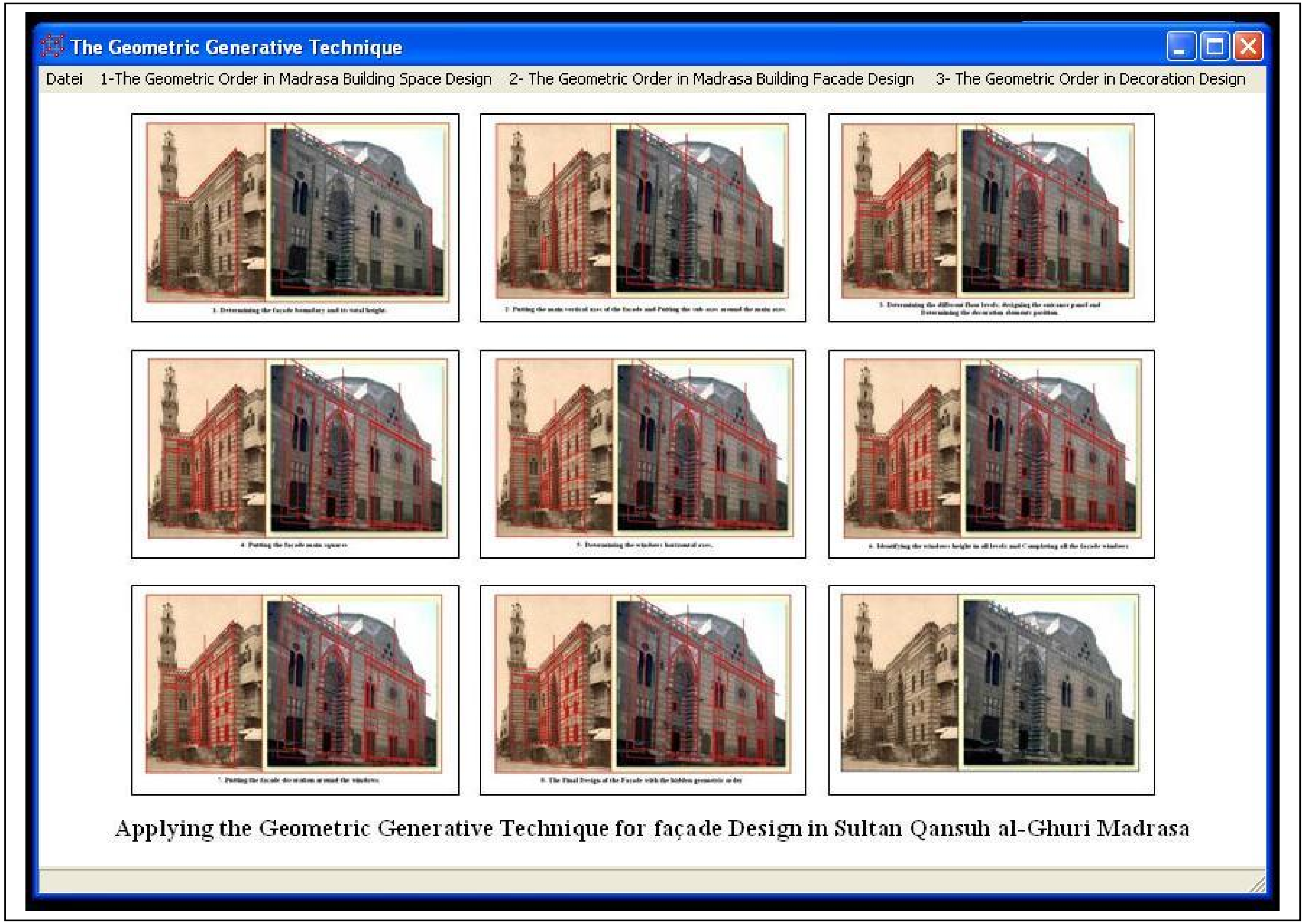
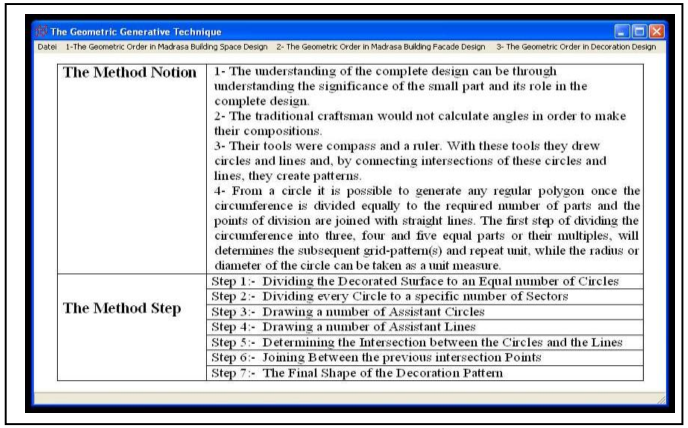


Figure 7-28 The geometric generative technique for facade design in Madrasa of Sultan Al-Ghuri building

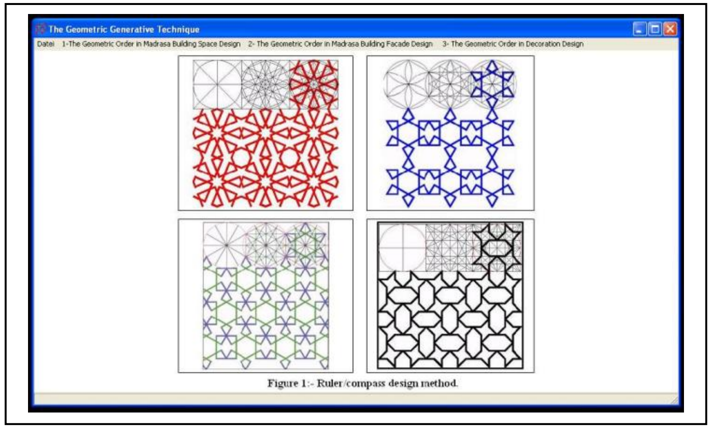
7.4.4. Applying the program in decoration geometric patterns design

The program presents six methods to the designer. All of them demonstrate the geometric order which controls the design of the decoration patterns.

Each method is explained inside the program in two sub-menus. The first one explains the method notion and the steps the designer can follow to generate the pattern. The second sub-menu presents the application of the method steps on the decoration pattern



a- Method notion and its steps



b- The method steps are applying in a decoration pattern.

Figure 7-29 The third main menu shows the geometric order in decoration design

7.5. Conclusion

The Computer-Aided Generator is a presentation tool for the building design steps. Its usefulness will be greater if it is used in teaching process inside institutions and architecture faculties. No special training is required in order to use the program efficiently.

Hence, the computer-aided generator is a useful tool both for the seasoned design architects and the students beginning their training in architecture design.

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